Solar Energy in Relation to Structural Engineering

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Table of Contents

The Basics of Solar Power

Solar power is increasingly popular among households around the world. However, many people may not understand how solar modules work, system design, factors that affect efficiency, or options for integrating a residential solar system with the existing power grid. This paper addresses all of these. First, let's look at how a solar module is manufactured to convert sunlight into electricity on an atomic level.

There are many material options for solar panel manufacturing, but silicon is the most popular due to its semiconductor qualities and its abundancy on Earth. Solar module silicon is primarily found in two forms: a monocrystalline wafer or a polycrystalline wafer. The monocrystalline wafer is comprised of a single crystal. Monocrystalline wafers are more desirable because the electrons excited by solar light have more space to move. In contrast, a polycrystalline wafer is comprised of many silicon crystals. While the polycrystalline wafer is cheaper to produce, its more complex structure obstructs the movement of the electrons excited by solar light. While both wafer structures make good semiconductors in a solar panel, the monocrystalline structure is preferred if cost is not an issue.

To make a solar module silicon wafer, a large block of silicon is cut into thin layers. These wafers are treated to form an internal diode. The diode allows electrical current to only flow in one direction. Next, the diode is placed between metal contacts, usually appearing as a metallic grid, which extracts the electrical current. The treated silicon is now prepared to convert sunlight to electricity and is sandwiched between two pieces of glass or plastic for protection. Combined, these components form a solar module. [3]. One solar module typically produces between 250-400 watts. Power output is dependent on efficiency, materials, and module size [9].

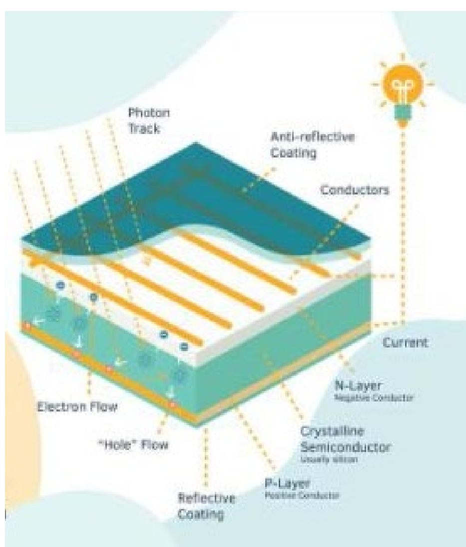

Figure 1: Solar PV Cell Diagram [11]

A solar module converts sunlight into electricity through semiconductors and band gaps. On an atomic level, all materials have a band gap, which is the distance between the outer electron rings of an atom. When a photon of light excites an atom, the electrons use that energy to jump from one ring to the next. A material's ability to do this classifies it as a conductor, semiconductor, or insulator. Materials with large band gaps require more energy for an electron to jump the band gap. Those materials make good insulators because energy does not flow through them easily. Conductors (like metal) have no band gap as the outer electron rings overlap allowing electrons to move freely between the two. The last group of materials is called semiconductors. In solar panels, their small band gap is utilized because solar photons provide enough energy to make electrons jump from one ring to the next. In that ring, the electrons join an electrical current. Another example of semiconductor use is light-emitting diodes (LEDs) which convert electricity into light by reversing this process. [1].

When solar photons encounter a solar module, the semiconductor's electrons use the energy to jump the band gap. In the next ring, these electrons become excess which traps them in the silicon wafer diode. This process (illustrated in Figure 1) creates an electrical current. The current traveling through the silicon is extracted by the module's grid of metallic contacts. This generates a direct current (DC), but to be utilized in households must be converted to an alternating current (AC). [5], [6]. An inverter is attached, which switches the flow of electricity back and forth very rapidly to convert the DC current into AC current. [4].

After passing through the inverter, the electricity can be utilized by a household or provided to the existing electrical grid. Energy can also be stored in an AC or DC battery on either side of the inverter [14]. This energy can be utilized during a power outage or when solar photons are not easily available, for example at night. The path of sunlight to home usage or grid injection is shown in Figure 2.

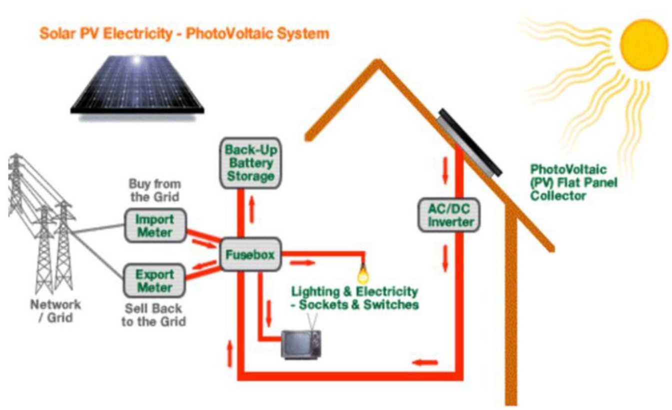

Figure 2: Schematic Example of a Solar Photovoltaic System [12]

Existing electric grids have started to accept the excess power created by household solar installations. Depending on the electric company servicing that house, excess created electricity can be provided to the grid two ways: through the same meter the house uses for receiving electricity or through a second electric meter. When using the same meter, the energy sent into the grid runs the electric meter backwards. This reduces the electric bill because it registers less power than was actually used. Companies that use a second meter typically record how much energy is contributed to the grid and award credits accordingly. For example, Pacific Gas & Electric uses the two-meter system and awards credits monthly. Credits are carried month to month and are reconciled on a 12-month basis. Each year, customers are awarded the choice of money back or allocation of their credits towards future electric bills. [8], [7].

Figure 3: Residential Roof Solar PV System [13]

When a solar system is designed for a household, a few factors are taken into consideration. First, roof space available for solar is determined in accordance with code required setbacks. Setback distances vary based on location, Figure 3 illustrates a generic rooftop solar PV layout with setbacks at the edges of the roof or ridgeline. Additionally, this figure shows roof spaces entirely without solar which could occur for reasons such as tree shading, system size, or building structure. Next, the solar designer determines desired energy production through monthly household energy consumption, often using information from an electric bill. The designer then decides which solar modules to procure based on module power output, useable roof space vs. module size, and price. Any of these three variables can be the controlling factor. Additionally, the cost of installation labor is considered in the project budget. [2].

Solar energy has many associated benefits, but unfortunately has drawbacks too. The biggest offender is solar cell efficiency. Cells are commonly about 18-22% efficient. The reduction in efficiency is largely attributed to the quantity of solar wavelengths outside the semiconductor's bandgap. Those wavelengths cannot excite electrons over the bandgap, and therefore do not create electricity [3]. Cell efficiency is measured through the ratio of sunlight in contact to the cell electrical output. Other factors that influence solar cell efficiency include heat, dirt, and shading. Excessive heat can reduce voltage by up to 30%. One solution currently in research is treatment of the module backsheet – its outer layer of protective material with the intent of keeping internal temperatures down. Solar modules are susceptible to "soiling" – dirt accumulating on the module – which can also impact efficiency by blocking sunlight from completely contacting the cell. To mitigate this issue, research is being conducted on dirt resistant glass treatments and improved maintenance techniques. The last big contributor to decreased solar cell efficiency is shading. When sunlight is not contacting the solar cell, electricity cannot be created. Intermittent shading (from clouds, etc.) reduces power output but the bigger culprit is permanent shading of module portions from objects like nearby trees, power poles, or other roof pieces. When portions of the module are in constant shade it creates a hot spot which causes an unbalanced current flow over the cell and damage. To mitigate this problem, research is being conducted on a "super-cell", which would have increased ability to balance current flow to keep unshaded portions functioning normally. Solving efficiency issues to increase solar yield will drop the overall cost of solar power. [10].

More affordable solar power will help to lead people on a path to clean energy. As explained in this paper, households can utilize the energy emitted from the sun - a clean and free energy source – to eliminate or greatly offset their traditional electricity usage. In a world where temperatures are increasing, the move to clean energy would be beneficial for all.

The Impact of Solar Energy

Solar energy is on the rise around the world. This increasing popularity should push people to discover its impacts on different sectors of their daily lives. In this paper, I will explore these impacts including economic, environmental, and political, both locally and globally. To begin, let us look at the economic impact of solar energy.

The major economic impacts of solar panels include the cost to the owner, long-term return of solar energy, and the effect on community economy. This is not an exhaustive list but one explored further through this project. The first item is the cost of solar energy to the owner, beginning with the price of the modules. A national average, taken by SunRun (a solar designer), found the average cost of a solar photovoltaic (PV) system to be $15,000 - $29,000, dependent on size [28]. After payment for units and installation, maintenance is the largest additional cost over the system's lifetime. Panels require cleaning roughly 2 times a year and general repairs as needed [28]. According to SunRun, cleaning costs around $150 and as needed repairs go for $200-$3,000 depending on the type of repair required [28].

To offset high initial and lifetime costs, many governmental authorities offer monetary incentives to increase the appeal of installing solar. For example, the U.S. federal government currently has a tax credit in place until the end of 2022 for 26% of final costs associated with any solar installation [27], [28]. Local authorities may also award incentives such as additional "tax credits, rebates, local electricity rates, [and] net energy metering (NEM)" [28]. Taking only the federal tax credit into consideration, the average initial solar costs mentioned above decrease by $3,900-$7,540.

High initial costs can create concern for how quickly solar energy can recoup that initial investment. According to SunRun, the "average payback period for a residential solar system is between 6-9 years" depending on the location [28]. Solar payback period is approximately the length of time necessary for pre-solar household monthly electric bills to total the price of the solar system.

To illustrate the payback period, a simplified example is shown below:

- ➔ According to the Comparative Analysis of Utility Services & Rates in California – a study conducted by the California Public Utilities Commission in 2015, the average

Californian household consumes 557kWh of electricity per month. One solar module will roughly create 45 kWh per month in California [28].

$$\frac{557\ kWh}{45\ kWh\ per\ Module} = 12.4\ Modules$$

As shown above, this household needs 13 modules to produce the equivalent of the average electricity consumption. Assuming the modules are 290 watts each, this system would be slightly under 4kW – this is on the smaller side of average for residential systems. A study done by EnergySage found that a 4kW system will cost $11,800 on average before the federal tax cut and $8,732 after [16].

- ➔ The installation of a solar system theoretically allows for no electric costs from an outside provider. However, many installations are grid connected and require meter checking thus accumulating a small bill each month so, this example is simplified.
- ➔ Many electric companies use a tiered pricing system, requiring the customer to pay more for increased usage. For the purposes of this example, an average price will be

used. The Global Energy Institute reports that the average price for electricity in California is 17.04 cents per kWh. [30]

$$\boxed{557\ kWh * \$0.1704 = \$94.91\ per\ month}$$

For this example, $94.91 is conservatively rounded to $100 per month for an electric bill without solar. This monthly saving will accumulate to $1,200 per year causing the payback period of the solar installation to be about 7.5 years (excluding maintenance).

$$\boxed{\$100\ per\ month * 12\ months = \$1{,}200\ savings\ per\ year}$$

$$\boxed{\frac{\$8{,}732\ initial\ cost}{\$1{,}200\ savings\ per\ year} = 7.3\ years\ for\ payback}$$

*This example is heavily simplified and does not account for smaller variations in cost, panel type, panel energy production, interest rates, and other location-based variations. The purpose is to provide a general breakdown for how a solar installation payback period can work.

After the payback period is complete, monthly savings will roughly equate to pre-solar energy bills. Household electricity costs will now only be the small metering service fee, small quantities of supplementary purchased electricity, and the cost of maintenance.

Community economy is also affected by the growing quantity of individual solar installations. Due to a reduction in clientele, electric companies are forced to raise their rates for continuing customers. Higher rates often drive additional customers away from this company thus raising rates and reducing clientele further. This cycle pushes electric companies to accommodate solar energy. An example of their effort is updating grids to work in two directions. This makes grid connection easily accessible and more fairly priced for clients with residential solar systems.

Leasing a solar energy system can be more affordable short term than buying because the upfront costs are low but the house owner does not receive the long term monetary benefits of lower electric bills. In this case, a solar PV system is designed for the customer's roof and installed at little to no cost. The downside is that created electricity is not the customer's but the leasing third party's. This option is good for those who cannot afford the initial cost of a solar PV system [17]. Additionally, people who desire an increase in clean energy usage but do not want or need the financial benefit of using solar energy for their own home could choose to lease instead [17]. When customers opt to buy a solar PV system the energy produced is fully theirs. This option is more expensive in the short term but pays itself off over time until the household energy bill is partially or fully covered by the solar panels.

The next solar impact is environmental. Overall, solar energy positively affects the environment; it is renewable, clean, and replaces many other non-renewable energy sources like fossil fuels. This picture of solar energy is widely presented, but there can be some negative repercussions. Although not often discussed, the first concern is toxic materials and chemicals used in manufacturing processes [32]. The United States regulates the use and disposal of these materials but, not every country that produces solar modules has these regulations, thus creating the potential for pollution from manufacturing [31].

Figure 4: Desert oasis: The plant's 8 million solar panels power about 160,000 California homes [33]

Globally, varying limitations placed on the hazardous manufacturing process has drawn attention to where panels are created. Countries with a less regulated manufacturing environment can produce solar modules for less money, making them more affordable to the customer. The competitive market increases the strain between the environmental benefits of solar panels and the environmental deficits created through manufacturing. Additionally, economic relationships between countries are affected as customers may what to purchase their solar modules from a country where production is less regulated and therefore cheaper.

Another negative environmental effect of solar energy is land clearing for solar farms, illustrated in Figure 4. Solar farms are used to create large quantities of solar energy in a single location. They are in rural, sunny areas and sprawl over large areas, typically 3.5-10 acres per megawatt [32]. The solar modules are typically mounted to a mechanical system that allows them to track the sun and absorb as much light as possible. Solar farms are extremely effective but require a large rural area to be cleared, displacing wildlife and local vegetation. Additionally, the land cannot be simultaneously used by agriculture because it is perpetually shaded by the modules [32]. Many residential installations are on rooftops which do not currently contain wildlife habitats or local foliage, solar panels are a great addition to this otherwise unused space [32].

Converting sunlight into electricity does not contribute to global warming however, all stages of the solar module lifespan must be considered in the analysis of their environmental effects [32]. As discussed, the beginning of a module's lifespan potentially creates pollution, but the end of a module's lifespan must also be analyzed. Currently, there are not many programs that recycle solar panels. Solar technology is very new so many panels have not reached the decommissioning point yet making the volume of recycled panels small [22]. In the future, implementing programs to recycle panels will be important because they contain precious metals and large amounts of silicon – materials that may not always be as abundant [22].

Solar panels have influenced the global and political landscapes as well. The topic of climate change and clean energy has increasingly affected political campaigns. Tax deductions or other monetary credits have made their way into local and federal regulations to incentivize a switch to solar power. Increased political strain has arisen as well, the division between household solar and public electricity companies is one example. Household installations help reduce the necessity for long power lines which have caused large wildfires in California in recent years [23]. Public utilities know the safety advantages of home solar energy production which should push them to fund this safer infrastructure [23].

The State of California has implemented a rigorous plan and goal for clean energy utilization in the coming years. This mandate forces public utilities to use Net Energy

Metering (NEM) for household solar system clients. Public electric utilities have fought the requirement for NEM stating it is “unfair to utilities and rate payers” [20]. Electric utilities oppose this system and have been lobbying against it for years [25]. NEM regulates how power utilities can “buy and sell energy from solar customers” and awards a monetary benefit to customers who send their excess electricity into the grid [18]. Utilities have been known to attach extra fees to solar use. Some utility companies offer homes without solar installations the option to buy electricity from clean sources, like solar farms, for a higher price. For homes with solar installations, utility companies have proposed monthly fees purely for being a solar customer [26]. Such behaviors can discourage customers from choosing solar energy.

In terms of overall utilization, there are a few reasons why solar panels are not yet on every home - one of the biggest being energy availability. Solar panels produce the most energy in the middle of the day when the sunlight is strongest, but the biggest demand for electricity is in the evenings when the sun sets. To overcome this, a system needs to utilize batteries to save power for later use. Some credit improved battery technology as the key to clean energy expansion. Without reliable batteries to store the solar power created during daylight, other forms of energy creation including fossil fuel will remain necessary when the sun goes down. [19].

Another factor holding solar energy back is cell efficiency. The current market average for module efficiency is 18-22% [24]. Research on physical panel design and new materials seeks to increase efficiency in solar panel yield, decreasing the price of switching to solar and providing wider availability [29]. Current knowledge indicates that cell efficiency and material toxicity seem to correlate. Some cells, like those made with cadmium-telluride, are more efficient, however cadmium is well known as a harmful pollutant [21]. An example of research into cell design is thin-film solar modules which use a fraction of the silicon needed for their crystalline counterparts [21]. The downside to this material usage is lower cell efficiency and lifespan. Additionally, solar paints, films, and coatings are being researched carrying potential for application on curved surfaces and windows or to wrap buildings. Efficiency and lifespan in this example are also decreased when compared to traditional modules [21]. Continued research has the potential to increase solar panel efficiency and versatility.

Solar energy is expanding around the world as the need for clean energy is becoming increasingly urgent. There are many options for clean energy production and of those, solar has become a viable and affordable option for communities. With continued research being conducted and more on the horizon, solar energy has great potential.

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SENIOR PROJECT CALCULATION PACKET

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California Polytechnic State University – SLO
Architectural Engineering Senior Project
2020-2021

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The purpose of this packet is to illustrate an industry style calculation that is necessary to install a roof mounted solar system. It is meant to represent an actual solar proposal with proprietary client information removed and is not meant to be used for construction. Much of the wording and formatting in this packet is courtesy of Engineered Power Solutions, Inc. as it was created out of an internship I completed with the firm.

Table of Contents

1.0 – RESULTS & PROJECT SCOPE

1.1 – Overview of Analysis & Results

- **Governing Building Code:**
  2019 *California Building Code*
  Based upon the 2018 *International Building Code (IBC)* which references the 2016 *Minimum Design Loads for Buildings and Other Structures* (Includes Supplements and Errata) by the American Society of Civil Engineers (ASCE 7-16)

- **Project Description:**
  The project consists of the addition of a new Photovoltaic (PV) solar racking system proposed to be placed upon (6) building sections of an existing shopping center. The calculation portion of this senior project is intended to address the structural aspects of the racking system at this project location, mainly the structural adequacy of the racking system and its anchorage to the structures as well as the structural adequacy of the existing buildings to support the imposed design loads (gravity, lateral, and anchorage loads) by the proposed PV system.

- **Project Purpose and Scope:**

  This senior project is intended to address the following items:

  - The structural justification of the solar attachment system and rails under the site-specific design loads prescribed by the governing building code.
  - Determination of the spacing of required attachment points to the roof and their locations based on the site-specific wind, snow, and seismic design requirements.
  - Justification of the anchorage design for the attachment points to the roof.
  - Justification of the inverter rack and anchorage design for the attachment points to the roof.
  - Checking the structural adequacy of the existing building for its ability to support the newly imposed PV design loads.
  - Ensuring the added PV system does not increase the lateral forces to the existing seismic resisting system by more than 10% thus allowing the existing lateral resisting system to remain unaltered.

- **Results:**
  I have determined that the proposed solar rail system and roof anchor attachments, if installed according to the parameters required in this calculation packet and on the plans, will be adequate to resist the imposed code prescribed design forces. It was also determined that the existing building will be able to support the proposed additional PV loads (as listed in this packet and the plans) per the current building code requirements and allowances.

2.0 – GRAVITY AND LATERAL CALCULATIONS

2.1 – Site Design Parameters

- **Building & Solar Addition Geometry:**

Overall Building Dimensions (approximate):	
Length (E-W):	Varies
Width (N-S):	Varies
Height (mean roof ht.):	Varies (≤ 40 ft.)
Proposed Solar Addition Geometry:	
Typical Module Type:	Standard 72 cell module
Module Size:	79.9”x39.7”, 56.2 lbs.
Number of Modules:	3,726 (Per Solar Designer)
Tilt of Modules:	10°

- **Wind Design Parameters:**

Wind Speed (3 second gust) (V):	94 MPH (per ATC)
Exposure Category	C
Wind Directionality Factor (Kd):	0.85
Velocity Pressure Exposure (Kh):	1.04 (conservative for all buildings)
Topographic Factor (Kzt):	1.00
Risk Category:	II
Guest Factor (G)	0.85
Ground Elevation Factor (Ke):	1.00 (conservative per Table 26.9-1)

- **Snow Loads:**

Ground Snow Load (p_g):	0 psf (per ATC)

- **Seismic Design Parameters:**

Seismic Design Category:	D
Site Class (Assumed per ASCE 7-16 11.4.3):	D

2.2 – Solar Racking Calculations

The racking manufacturer has provided me with the rail section properties, material specifications, and required structural design information. I have reviewed the provided information and have performed independent structural calculations on the site-specific conditions of this project as shown in the following analysis.

2.2.1 – Roof Zones

- **Determination of Dead Loads:**
  - Module Weight = 56.2 lbs. / ((79.9 x 39.7)/(1ft^2 / 144in^2)) = 2.6 psf
    - 2.6 psf * 3.3 ft = 8.6 plf
    - Max Load to Rail = Use 9.0 plf
- **Determination of Snow Loads:**
  - Roof Snow Load = p_f = 0 psf
    - Max Load to Rail = 0 psf * 3.3 ft. = 0 plf
- **Determination of Wind Forces per ASCE 7-16 Section 29.4.3 <u>(Rail Only):</u>**
  - q = 20.0 psf (ASCE 26.10.2)
  - p = $qGC_{rn}(\gamma_c)(\gamma_p)(\gamma_E)$ (ASCE 29.4.3 and Figure 29.4-7)
  - γ_p = 1.2 (conservative in many locations)
  - γ_c = 1.0
  - γ_E = 1.5 (conservatively used for all array rows)

<u>Rail Load (Shows rail tributary area for ≈30 ft^2 / ≈100 ft^2)</u>

- Roof Zone 1:
  - GC_{rn} (Uplift): 1.1 / 0.75
    - p (Uplift) = 39.6 psf / 27.0 psf
    - Max Uplift to Rail = 131.1 plf / 89.4 plf
- Roof Zone 2:
  - GC_{rn} (Uplift): 1.55 / 1.1
    - p (Uplift) = 55.8 psf / 39.6 psf
    - Max Uplift to Rail = 184.7 plf / 131.1 plf
- Roof Zone 3:
  - GC_{rn} (Uplift): 1.85 / 1.25
    - p (Uplift) = 66.6 psf / 45 psf
    - Max Uplift to Rail = 220.5 plf / 149 plf

- **Determination of Wind Forces per ASCE 7-16 Section 29.4.3 <u>(Anchorage Only):</u>**
  - q = 20.0 psf (ASCE 26.10.2)
  - p = $qGC_{rn}(\gamma_c)(\gamma_p)(\gamma_E)$ (ASCE 29.4.3 and Figure 29.4-7)
  - γ_p = 1.2 (conservative in many locations)
  - γ_c = 1.0
  - γ_E = 1.5 (conservatively used for all array rows)

<u>Anchorage Uplift</u>

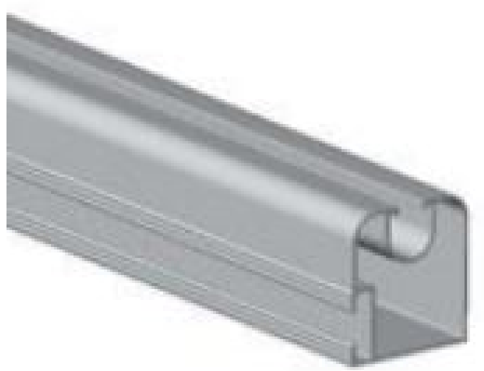
- Roof Zone 1 (Effective Wind Area: 19.975 ft^2):
  - GC_{rn} (Uplift): -1.2
  - p (Uplift) = -43.2 psf
  - Tributary Area to Anchor: 19.975 ft^2
  - Max Uplift to Anchor (Unfactored) = -863 lbs.
  - Module + Racking Weight: 3.0 psf
  - Load Combo (0.6D + 0.6W):
    → (0.6 * 60 lbs.) + (0.6 * -863 lbs.) = **-482 lbs.**

- Roof Zone 2 (Effective Wind Area 16.65 ft^2):
  - GC_{rn} (Uplift): -1.7
  - p (Uplift) = -61.2 psf
  - Tributary Area to Anchor: 16.65 ft^2
  - Max Uplift to Anchor (Unfactored) = -1019 lbs.
  - Module + Racking Weight: 3.0 psf
  - Load Combo (0.6D + 0.6W):
    → (0.6 * 50 lbs.) + (0.6 * -1019 lbs.) = **-582 lbs.**

- Roof Zone 3 (Effective Wind Area: 13.32 ft^2):
  - GC_{rn} (Uplift): -2.0
  - p (Uplift) = -72 psf
  - Tributary Area to Anchor: 13.32 ft^2
  - Max Uplift to Anchor (Unfactored) = -960 lbs.
  - Module + Racking Weight: 3.0 psf
  - Load Combo (0.6D + 0.6W):
    → (0.6 * 40 lbs.) + (0.6 * -960 lbs.) = **-552 lbs.**

2.2.2 – Racking Calculations

The roof zones prescribed by ASCE 7-16 allow for different rail spans dependent on the forces present in that zone. Consequently, I have reviewed each rail span and loading condition for structural adequacy using RISA. The RISA analysis of the worst-case uplift and downward forces on the rails is located in Appendix A. This includes dead, wind, and snow applied using the combinations in the governing building code.



Rail Section Properties:

Ix = 0.24728 in4
Sx = 0.24687 in3

Iy = 0.20345 in4
Sy = 0.21739 in3

Figure 5: Aluminum Rail Section

Per the Aluminum Design Manual, the allowable stress for the proposed rail (6005A-T61 Aluminum) is 17.9 ksi.

The maximum moment among all rail spans and loading conditions (per the RISA Printout) is 353 lb-ft which, based on the section modulus shown above of 0.246 in^3, produces a stress of 17.2 ksi in the rail. The produced stress is less than the allowable stress of 17.9 ksi.

Therefore, the rail is adequate for the proposed design forces using the following maximum rail spans dependent on roof zone:

- **Zone 1: 6’-0” o.c. – Max. Cantilever = 2’-6” (30”)**
- **Zone 2: 5’-0” o.c. – Max. Cantilever = 2’-0” (24”)**
- **Zone 3: 4’-0” o.c. – Max. Cantilever = 1’-6” (18”)**

2.2.3 – Racking Leg Design

The solar modules are placed on a tilt leg system that connects them with the existing building roof below. These tilt legs have the capacity to fail under the proposed loads and are therefore checked for structural adequacy as well. The RISA printout showing the adequacy of the tilt legs with worst-case vertical loads is located in Appendix A.

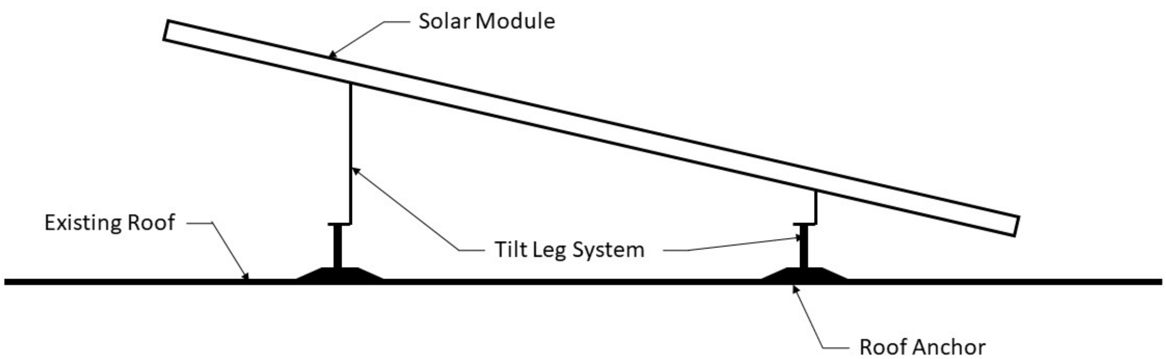


Figure 6: Tilt Leg System Diagram

<u>Gravity and lateral Loads</u>

Tributary width: (zone 2) = 5 ft. (worst-case)
*Wind GC_{rn} factors are based on a 30 ft^2 effective wind area based on the maximum 5 ft. span in zone 2 → GC_{rn} = 1.55

- Gravity Load (module+racking): 5 ft * 3.0 psf = **15.0 plf**
- Wind Load: 5 ft. * -55.8 psf = -**279 plf**
- Snow Load: 5 ft. * 0 psf = **0 plf**

*I have checked racking for the 6” standoffs

2.2.4 – Uplift Calculations

Due to differing spans and loads in each roof zone, I have reviewed all anchorage conditions to discern the worst-case uplift force experienced in each zone. These forces are as follows: 552 lbs. (Zone 3), 582 lbs. (Zone 2), and 482 lbs. (Zone 1). From this data, I have decided to design the anchorage to be able to withstand the worst-case uplift force out of all roof zones, 582 lbs. in Zone 2, as such, the same anchorage can be used throughout the entire mounting system regardless of roof zone. The uplift force is resisted by the roof anchor and screws, with the screw quantity dependent on the connecting framing. For existing rafters/purlins use (2) #14 wood screws with min embedment of 2.5", for existing plywood/OSB deck (19/32" minimum deck thickness) use (6) #14 wood screws, or for steel deck (20 ga. min) use (6) #14 screws. The justification of these connections is shown below.

<u>Option A (screws into rafters/purlins – 2.5" min embedment – Center on Rafter)</u>

(2) #14 Wood Screws into wood rafters (2.5'' embedment min, G=0.5, C_D = 1.6):

- 2 screws * 172 lbs per in *2.5'' * 1.6 = 1376 lbs. $\geq$ 582 lbs. → **OK**
- (61.2 ft-lb * 12) / 3.75" = 195.9 lbs (worst-case moment for Zone 2)
  195.9 lbs / 2 screws = 97.9 lbs. per screw
  97.9 lbs/screw + (746 lbs/2 screws) =471 lbs/screw $\leq$ 688 lbs./screw → **OK**

<u>Option B (screws into 19/32" min. plywood/OSB – tapered tip to fully protrude beyond underside of plywood/OSB deck):</u>

(6) #14 Wood Screws into OSB (19/32 embedment min., G=0.50, C_D = 1.6):

- 6 screws * 172 lbs per in *19/32" * 1.6 = 980 lbs. $\geq$ 582 lbs. → **OK**
- (61.2 ft-lb * 12) / 3.75" =195.9 lbs (worst-case moment for Zone 2)
  195.9 lbs / 6 screws = 32.7 lbs per screw
  32.7 lbs/screw + (582 lbs/6 screws) = 130 lbs/screw $\leq$ 163 lbs./screw → **OK**

Option C (screws into 20 ga. min. steel deck):

(6) ¼" TEK Screws (or approved equal) into steel deck – Per ICC report ESR-1976.

- (6) screws * 115 lbs./screw = 690 lbs. $\geq$ 582 lbs. → **OK**

Roof Anchorage (Sample Roof Anchor):
Sample Roof Anchor (Per manufacturer testing and specifications):

- Ultimate load (avg): $\frac{4716 \text{ lbs.}}{582 \text{ lbs}}$ = 8.1 factor of safety → **OK**

2.3 – Inverter Rack, Equipment & Anchorage

- Maximum Wind Uplift Load (for roof mounted inverter racks):
  - $F = q_zGC_fA_f$ (ASCE 7-16 Equation 29.4-1)
    - $q_h = 0.00256*1.04*1.00*0.85*1.0*94^2 = 20.0$ psf
    - G = 0.85 (ASCE 7-16 Section 26.11)
    - C_f (vert.) = 2.0 (ASCE 7-16 Figure 29.4-1)
    - C_f (horiz.) = 2.0 (ASCE 7-16 Figure 29.4-1)
    - A_f (vert.) = 3.3 ft. x 2 ft. = 6.6 ft^2
    - A_f (horiz.) = 0.85 ft. x 2 ft. = 1.7 ft^2
  - F (vert.) = 20.0 psf * 0.85 * 2.0 * 6.6 ft^2 = **225 lbs.**
  - F (horiz.) = 20.0 psf * 0.85 * 2.0 * 1.7 ft^2 = **57.8 lbs.**
  - Height above roof to center of mass: 2.5 ft. (max)
  - Min. Distance between support legs: 3.0 ft. (min)

  - Uplift load per side applied using governing load combination 0.6D – 0.6W:
    - 0.6(225 lbs.) + 0.6(57.8 lbs. * 2.5 ft. / 3.0 ft.) – 0.6(150 lbs.) /2 = 119 lbs.
    - Therefore, the total uplift to a single anchor is 119 / 2 = **59.5 lbs.**

- Maximum Seismic Loads:

  Using the satellite coordinates of the site, the spectral accelerations have been calculated. Below is a summary of those worst-case accelerations:

  - S_s = 0.500 (Per ATC Website)
  - S_1 = 0.200 (Per ATC Website)
  - Site Class = D (per ASCE 7-16 11.4.3)
  - F_a = 1.500 (per ATC Website)
  - F_v = *null (per ATC Website)
  - S_{MS} = 0.750 (S_s*F_a)
  - S_{M1} = *null (S_1*F_v)
  - S_{DS} = 0.500 (2/3*S_{MS})
  - S_{D1} = *null (2/3*S_{M1})

  Based on these accelerations the Seismic Design Category of this site is “D”. Using a seismic importance factor of 1.00, a_p of 1.0 and an R of 2.5 based on ASCE 7-16 Table 13.6-1 for Nonstructural Components, the base shear can be calculated:

  - Base Shear (F_p) = 0.2W_p (per Equation 13.3-1)
    - W_p = weight (dead load)

Based on the equipment weight, the seismic forces have been calculated below:

- Seismic force on inverter (Strength Level):
  - 0.2 * 150 lbs. = **30 lbs.**
- Vertical Seismic force (per 12.4.2.2):
  - 0.2*0.500 *150 = **15 lbs.**

- Uplift load per side applied using governing load combination 0.6D – 0.7E:
  - 0.7(15 lbs.) + 0.7(30 lbs. * 2.5 ft. / 3.0 ft.) – 0.6(150 lbs.) / 2 = -17 lbs.
  - Therefore, the total uplift to a single anchor is -17 / 2 = **-8.5 lbs.**

Option A (screws into rafter/purlin – 2.5” min embedment)

(2) #14 Wood Screws into wood block (2.5’’ embedment min., G=0.5, C_D = 1.6):
- 2 screws * 172 lbs per in *2.5’’ * 1.6 = 1376 lbs. ≥ 59.5 lbs. → **OK**

Option B (screws into plywood – 19/32” min embedment)

(6) #14 Wood Screws into plywood (19/32 embedment min., G=0.42, C_D = 1.6):
- 6 screws * 172 lbs per in *19/32” * 1.6 = 980 lbs. ≥ 59.5 lbs. → **OK**

Option C (screws into 20 ga. min. steel deck)

(7) ¼” TEK Screws (or approved equal) into steel deck – Per ICC report ESR-1976.
- (7) screws * 115 lbs./screw = 805 lbs. ≥ 59.5 lbs. → **OK**

Roof Anchorage (Sample Roof Anchor)

- Sample Roof Anchor (Per manufacturer testing and specifications):
  - Ultimate load (avg): $\frac{4716\text{ lbs.}}{59.5\text{ lbs}}$ = 79.3 factor of safety → **OK**

2.4 – Adequacy of the Existing Buildings

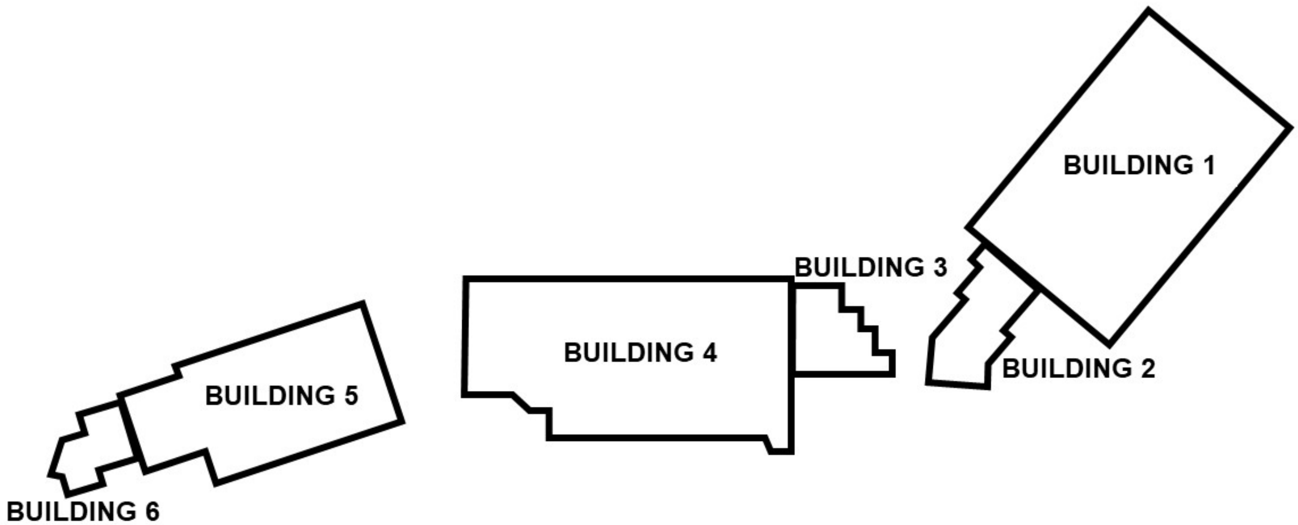


Figure 7: Building Layout with Labels – NTS

2.4.1 – Existing Roof Framing

According to the visually observable as-built information obtained from an in-person site visit or existing construction documents (plans) and/or as provided the existing roof framing consists of:

Framing / Estimated Dead Load:

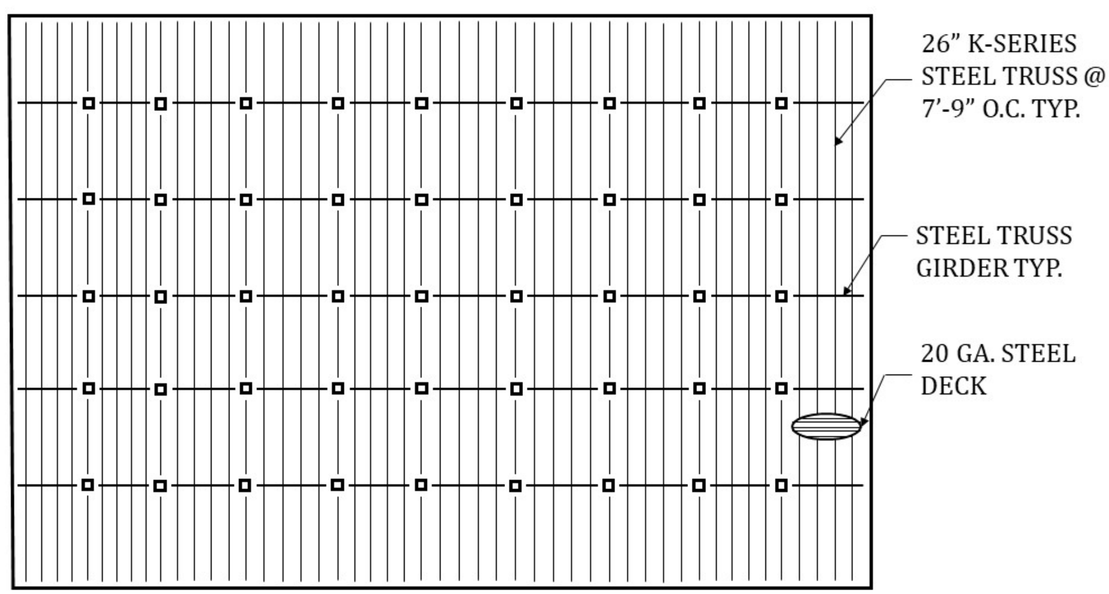


Figure 8: Building 1 Rough Framing Plan – NTS

- Building 1:
    - Roof Dead Load: 16 psf max./12 psf min.
    - Composition roofing
    - 20 ga. Steel deck
    - Rigid Insulation
    - 26” K-Series steel truss @ 7’-9” o.c. spanning 38 ft. max.
    - Steel truss girders spanning 60’ max.
    - Drop T-Bar ceiling
    - Sprinklers
    - M/E/P
    - Misc.

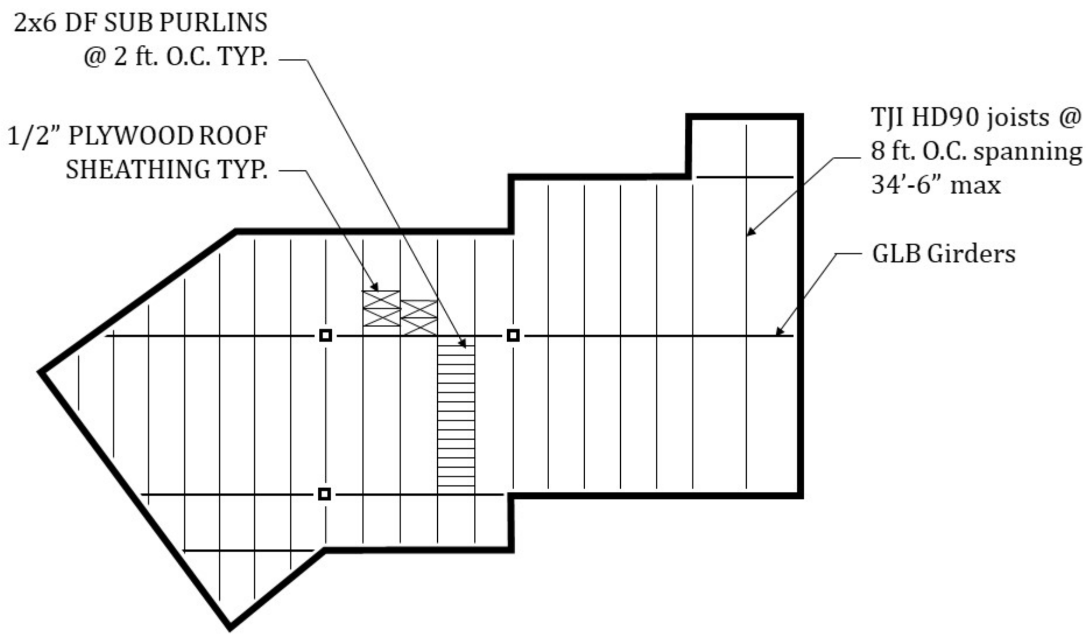


Figure 9: Building 2 Rough Framing Plan – NTS

- Building 2:
    - Roof Dead Load: 13 psf max./10 psf min.
    - Composition roofing
    - ½" Plywood sheathing
    - Insulation
    - 2x6 Sub DF No. 1 purlins @ 2 ft. o.c. spanning 8 ft.
    - (Various sizes) TJI HD90 joists @ 8 ft. o.c. spanning 34'-6" max.
    - (Various sizes) GLB girders (various spacing and spans)
    - Drop T-Bar ceiling
    - Sprinklers
    - M/E/P
    - Misc.

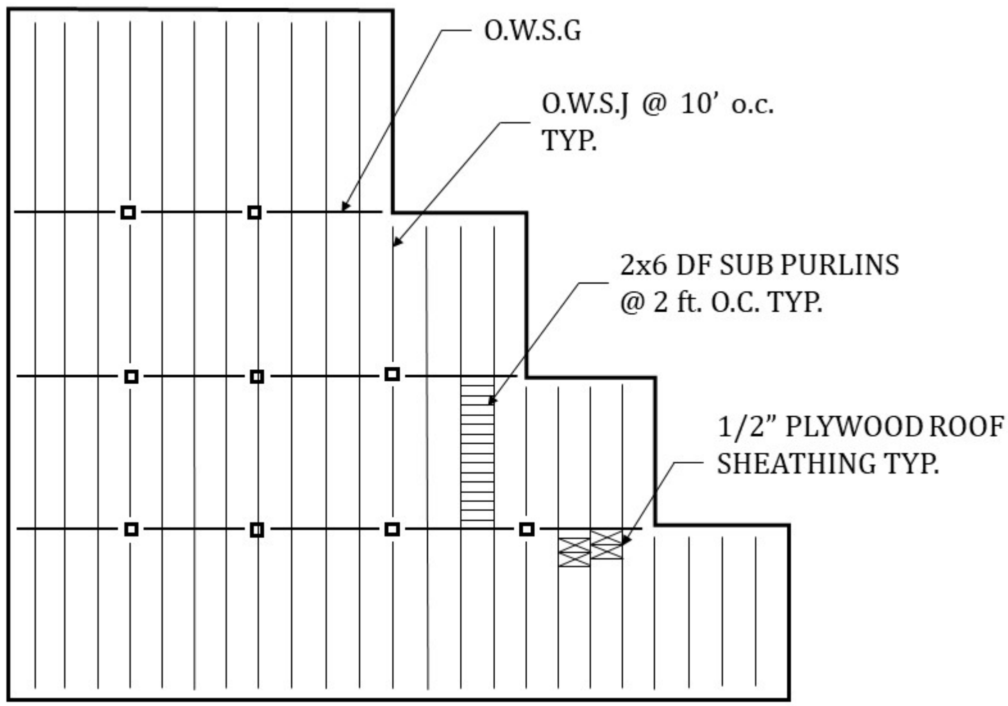


Figure 10: Building 3 Rough Framing Plan – NTS

- Building 3:
    - Roof Dead Load: 13 psf max./11psf min.
    - Membrane roofing
    - ½" Plywood sheathing
    - 2x6 Sub purlins @ 2 ft. o.c. spanning 10 ft.
    - O.W.S.J. @ 10 ft. o.c. spanning 32 ft.
    - O.W.S.G. (Various Spacing) spanning 32 ft.
    - Insulation
    - Sprinklers
    - M/E/P
    - Drop T-Bar ceiling (limited areas)
    - Misc.

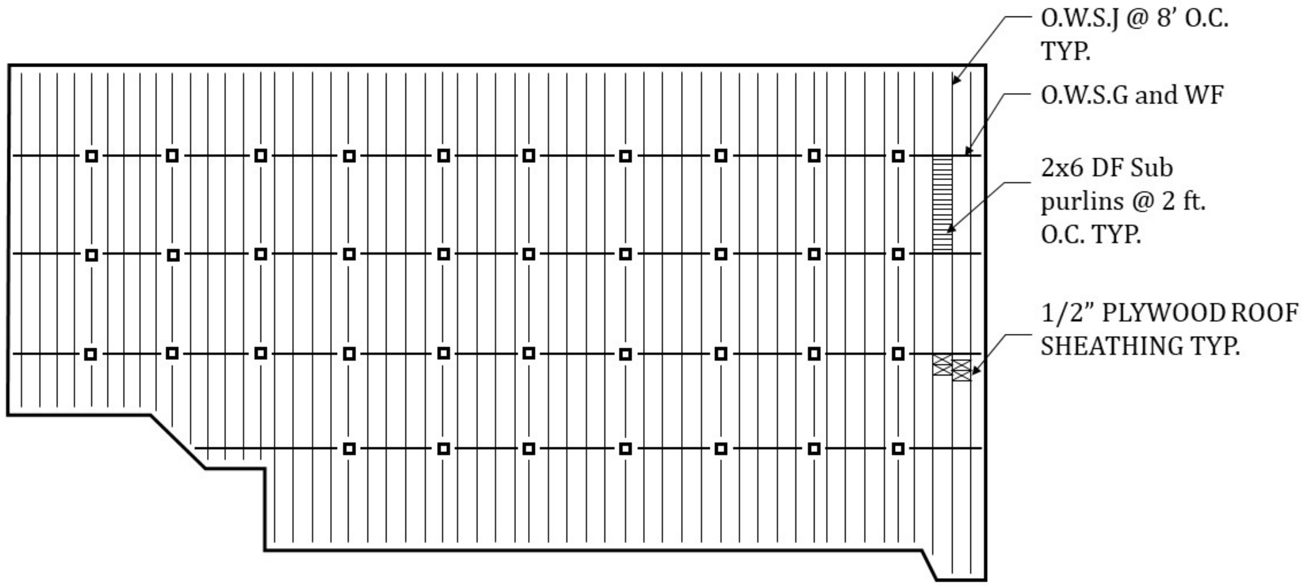


Figure 11: Building 4 Rough Framing Plan – NTS

- Building 4:
    - Roof Dead Load: 13 psf max./11psf min.
    - Membrane roofing
    - ½" Plywood sheathing
    - 2x6 Sub purlins @ 2 ft. o.c. spanning 8 ft.
    - O.W.S.J. @ 8 ft. o.c. spanning 40 ft.
    - O.W.S.G. and Wide Flange Girders spanning 45 ft. max.
    - Insulation
    - Sprinklers
    - M/E/P
    - Drop T-Bar Ceiling (some sections)
    - Misc.

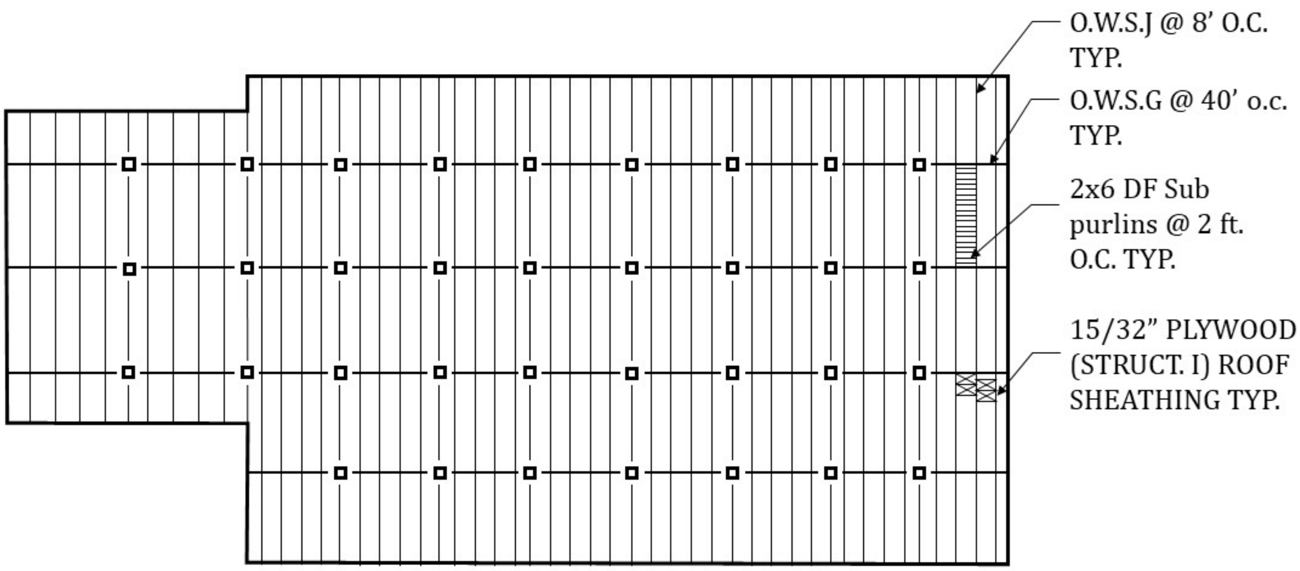


Figure 12: Building 5 Rough Framing Plan – NTS

- Building 5:
  - Roof Dead Load: 12 psf max./10 psf min.
  - Composition roofing
  - 15/32" Plywood (struct. I) roof sheathing rated 32/16
  - Insulation
  - 2x6 DF No. 1 Sub purlins @ 2 ft. o.c. spanning 8 ft.
  - O.W.S.J. @ 8 ft. o.c. spanning 40 ft.
  - O.W.S.G. @ 40 ft. o.c. spanning 40' max.
  - Drop T-Bar ceiling (some sections)
  - Sprinklers
  - M/E/P
  - Misc.

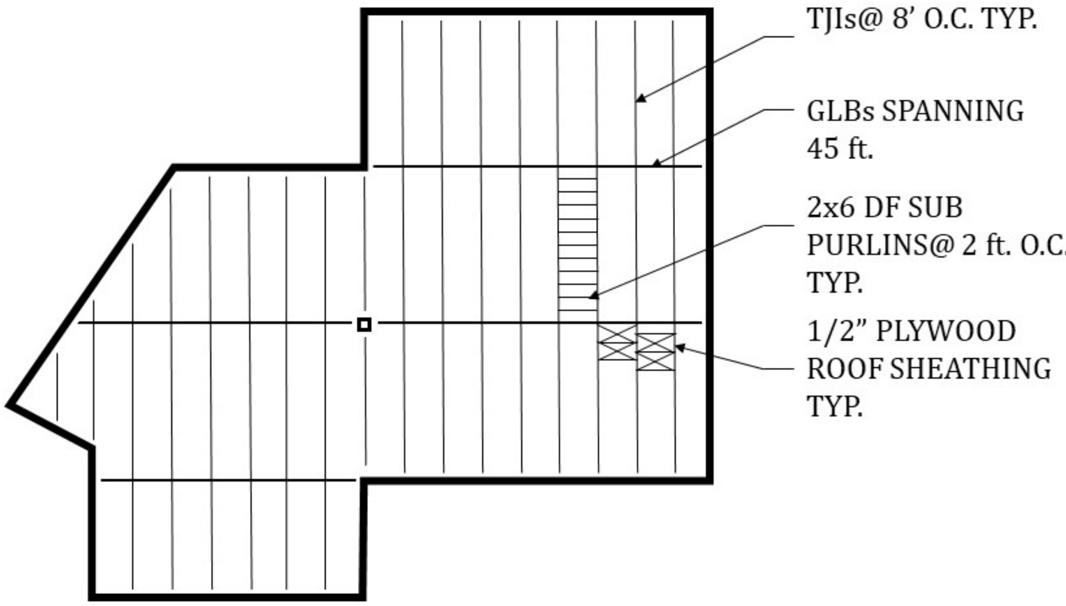


Figure 13: Building 6 Rough Framing Plan – NTS

- Building 6:
    - Roof Dead Load: 10 psf
    - Membrane roofing
    - ½" Plywood sheathing
    - 2x6 Sub purlins @ 2 ft. o.c. spanning 8 ft.
    - TJIs @ 8 ft. o.c. spanning 20 – 24 ft.
    - GLBs spanning 45 ft.
    - Insulation
    - Sprinklers
    - M/E/P
    - Misc.

I have been informed that all buildings may be subject to re-roofing prior to the PV module addition. I have been told to assume a new roofing weight of 0.291 psf over the full building area. This new roofing weight has been included in the calculations regarding new loads to be supported by the existing buildings. [Note: if existing roofing is removed, the removed weight can be subtracted from the following psf values and total weights in the seismic addition section. I have conservatively assumed existing roofing will remain in all cases in the following calculations. The engineer has conservatively used 3.0 psf as the module + racking wt.]

<u>Worst Case PV Load:</u> 3.0 psf + 0.291psf (added roofing) = 3.29 psf → **Use 3.5 psf**
(This is conservative over larger array areas as walkways between module rows decrease distributed PV + roofing load to ≈ 2 psf)

In addition to the existing dead loads, newly proposed PV systems, and applicable roof live load (required to be applied only on areas not covered by new PV since the PV is less than 24" above the roof surface – see note below), I have also included the vertical seismic load effects per ASCE 7-16, Section 12.4.1 conservatively using the worst-case dead load for all buildings:

- $E_{v(\text{Worst Case})} = 0.2(S_{DS})D = 0.2*0.500*(16 \text{ psf} + 3.5 \text{ psf}) = 1.95 \text{ psf}$ → **Use 2.0 psf**

Based on the building code definition of a roof live load, Interpretation of Regulation document IR 16-8 (Solar Photovoltaic and Thermal Systems Review and Approval Requirements), and CBC/IBC Section 1607.12.5.1, "areas where the clear space between the panels and the rooftop is not more than 24 inches shall be considered inaccessible", and therefore is not subjected to a roof live load.

Therefore, it is permitted to analyze the existing buildings' roof framing based on the existing roof dead loads and the applicable roof live loads based on the specific amounts of PV system coverage tributary to each framing member… but for this project, I have conservatively used the following percentages of roof live loads:

- Building 1:
  - Roof Steel Deck: Full roof live load conservatively applied regardless of PV coverage.
  - O.W.S.J: Roof live load applied in areas where solar is not present, Appendix A contains RISA printouts showing 5 different loading scenarios: original – no solar coverage present, 100% solar coverage, 75% solar coverage, 50% solar coverage, and 25% solar coverage. Roof live load reductions only taken based on tributary area (per code).

- Building 2:
  - 2x6 Rafters: Full roof live load (conservatively applied even under module areas).
  - TJIs: Roof live load applied in areas where solar is not present, Appendix A contains RISA printouts showing 5 different loading scenarios: original – no solar coverage present, 100% solar coverage, 75% solar coverage, 50% solar coverage, and 25% solar coverage. Roof live load reductions only taken based on tributary area (per code).
  - GLB Girders: Full roof live load (conservatively applied even under module areas) applied to the cantilever condition. 25% of roof live load (applied under module areas, accounting for full solar coverage) applied to the simply supported condition. Roof live load reductions only taken based on tributary area (per code).

- Building 3:
  - 2x6 Rafters: Full roof live load (conservatively applied even under module areas).
  - O.W.S.J: Roof live load applied in areas where solar is not present, Appendix A contains RISA printouts showing 5 different loading scenarios: original – no solar coverage present, 100% solar coverage, 75% solar coverage, 50% solar coverage, and 25% solar coverage. Roof live load reductions only taken based on tributary area (per code).

- Building 4:
  - 2x6 Rafters: Full roof live load (conservatively applied even under module areas).
  - O.W.S.J: Roof live load applied in areas where solar is not present, Appendix A contains RISA printouts showing 5 different loading scenarios: original – no solar coverage present, 100% solar coverage, 75% solar coverage, 50% solar coverage, and 25% solar coverage. Roof live load reductions only taken based on tributary area (per code).

- Building 5:
  - 2x6 Rafters: Full roof live load (conservatively applied even under module areas).
  - O.W.S.J: Roof live load applied in areas where solar is not present, Appendix A contains RISA printouts showing 5 different loading scenarios: original – no solar coverage present, 100% solar coverage, 75% solar coverage, 50% solar coverage, and 25% solar coverage. Roof live load reductions only taken based on tributary area (per code).

- Building 6:
  - 2x6 Rafters: Full roof live load (conservatively applied even under module areas).
  - TJIs: Roof live load applied in areas where solar is not present, Appendix A contains RISA printouts showing 5 different loading scenarios: original – no solar coverage present, 100% solar coverage, 75% solar coverage, 50% solar coverage, and 25% solar coverage. Roof live load reductions only taken based on tributary area (per code).
  - GLB Girders: Full roof live load (conservatively applied even under module areas). Roof live load reductions only taken based on tributary area (per code).

For all framing members, a roof snow load of 0 psf has been applied per ASCE 7 and the ATC website.

The following pages and the RISA printouts in Appendix A show the adequacy of the existing rafters, joists, beams, and girders as applicable for Buildings 1-6 with the governing loading conditions for each member type under current code requirements.

The TJI and glu-lam members are modeled under (5) different loading scenarios. This is per the current code (CBC) and IEBC, as any existing gravity element where the addition does not increase the load more than 5% shall be permitted to remain unaltered. I have provided the following comparison which shows the additional proposed solar would be in compliance with the code requirements for gravity additions. As shown for all conditions, the design stresses (moment and shear) on the TJI and glu-lam members are lower or less than a 5% increase on all cases where solar PV is being added which per code allows the existing members to remain unaltered.

Member results shown on "Unity Check" and "Shear Check" RISA printouts show the demand capacity ratio for moment and shear respectively.

***It is the responsibility of the Racking designer to ensure the PV load + added roofing load does not exceed 3.5 psf.**

Building 1 Joist

- Original Design Shear vs. Worst-Case PV Shear:
  - 5,035 lbs. vs. 5,089 lbs. → 1.1% $\leq$ 5% → OK
- Original Design Moment vs. Worst-Case PV Moment:
  - 47,833 #-ft vs. 47,411 #-ft → No net increase → OK

Building 2 Joist

- Original Design Shear vs. Worst-Case PV Shear:
  - 4,140 lbs. vs. 4,200 lbs. → 1.5% $\leq$ 5% → OK
- Original Design Moment vs. Worst-Case PV Moment:
  - 35,708 #-ft vs. 35,410 #-ft → No net increase → OK

Building 3 Joist

- Original Design Shear* vs. Worst-Case PV Shear:
  - 4,896 lbs. vs. 4,982 lbs. → 1.8 < 5% → OK
- Original Design Moment vs. Worst-Case PV Moment:
  - 39,168 #-ft vs. 39,026 #-ft → No net increase → OK

Building 4 Joist

- Original Design Shear vs. Worst-Case PV Shear:
  - 4,900 lbs. vs. 4,994 lbs. → 1.9% ≤ 5% → OK
- Original Design Moment vs. Worst-Case PV Moment:
  - 49,000 #-ft vs. 48,898 #-ft → No net increase → OK

Building 5 Joist

- Original Design Shear vs. Worst-Case PV Shear:
  - 4,740 lbs. vs. 4,834 lbs. → 2.0% ≤ 5% → OK
- Original Design Moment vs. Worst-Case PV Moment:
  - 47,400 #-ft vs. 47,298 #-ft → No net increase → OK

Building 6 Joist

- Original Design Shear vs. Worst-Case PV Shear:
  - 3,408 lbs. vs. 3,003 lbs. → No net increase → OK
- Original Design Moment vs. Worst-Case PV Moment:
  - 20,448 #-ft vs. 17,614 #-ft → No net increase → OK

2.4.2 – Weight Added to Existing Building

Seismic Mass

Per IBC Section 3404.4, Alterations adding less than 10% of the original design dead load to a lateral load-carrying element are permitted to remain unaltered. The overall mass of the roof has been compared to the mass being added by the new PV system since the PV mass distribution appears to be relatively equally distributed over the existing roof areas on all buildings.

I have estimated the roof masses, conservatively ignoring exterior in-plane wall weight, interior partitions, and roof towers/awnings and determined the roof of the existing structure sections to have a dead weight of:

Roof Dead Loads:

- Building 1: 901 kips (conservatively uses 12 psf DL)
- Building 2: 79 kips (conservatively uses 10 psf DL)
- Building 3: 81 kips (conservatively uses 11 psf DL)
- Building 4: 825 kips (conservatively uses 11 psf DL)
- Building 5: 423 kips (conservatively uses 10 psf DL)
- Building 6: 46 kips

Out-of-plane exterior wall weight tributary to roof level:

- Building 1: 650 kips (assumes 8" thick wall)
- Building 2: 18 kips (conservatively assumes 2x4)
- Building 3: 162 kips (assumes 8" thick CMU wall)
- Building 4: 454 kips (assumes 8" thick CMU wall)
- Building 5: 259 kips (assumes medium density block)
- Building 6: 23.5 kips (assumes wood framed, plaster one side)

Total existing building weight tributary to roof:

- Building 1: 1,551 kips
- Building 2: 97 kips
- Building 3: 243 kips
- Building 4: 1,279 kips
- Building 5: 682 kips
- Building 6: 69.5 kips

Estimated PV Weight Added (3.0 psf x number of modules x module area)

- Building 1: 83,270 lbs.
- Building 2: 5,950 lbs.
- Building 3: 5,950 lbs.
- Building 4: 99,920 lbs.
- Building 5: 48,770 lbs.
- Building 6: 2,380 lbs.

Estimated Roofing Weight Added (0.3psf x roof area)

- Building 1: 22,600 lbs.
- Building 2: 2,370 lbs.
- Building 3: 2,220 lbs.
- Building 4: 22,500 lbs.
- Building 5: 12,700 lbs.
- Building 6: 1,380 lbs.

Conduit and inverter weight:

(Conduit weight provided – the engineer has used 150 lbs. per inverter):

- Building 1: 3,050 lbs. + 900 lbs. = 3,950 lbs.
- Building 2: 50 lbs. + 150 lbs. = 200 lbs.
- Building 3: 150 lbs. + 150 lbs. = 300 lbs.
- Building 4: 3,150 lbs. + 1,050 lbs. = 4,200 lbs.
- Building 5: 1,400 lbs. + 600 lbs. = 2,000 lbs.
- Building 6: 20 lbs. + 0 lbs. = 20 lbs.

*I am to be notified in writing if the conduit is to weigh more than what is estimated above.

Estimated Total PV, roofing, and equipment weight added:

- Building 1: 109,820 lbs.
- Building 2: 8,520 lbs.
- Building 3: 8,470 lbs.
- Building 4: 126,620 lbs.
- Building 5: 63,470 lbs.
- Building 6: 3,780 lbs.

Therefore, the rooftop addition weights must have a total mass of less than 10% of the existing seismic mass:

- **Building 1:** **109,820 lbs. ≤ 155,100 lbs. → OK**
- **Building 2:** **8,520 lbs. ≤ 9,700 lbs. → OK**
- **Building 3:** **8,470 lbs. ≤ 24,300 lbs. → OK**
- **Building 4:** **126,620 lbs. ≤ 127,900 lbs. → OK**
- **Building 5:** **63,470 lbs. ≤ 68,200 lbs. → OK**
- **Building 6:** **3,780 lbs. ≤ 6,950 lbs. → OK**

Based on these values, the engineer has determined that the PV additions will not increase the lateral loads by more than 10% allowing the existing lateral resisting system to remain unaltered per code.

VBA Code in Relation to Structural Engineering

The Necessity and Inspiration for this Project

Shortly after beginning my summer internship, my boss proposed automating the firm's tedious calculation process for standard jobs. As it stood, the firm used a simple Word document. While this method presented a pristine and organized structural calculation packet to clients, it required some tedious work that reduced the overall efficiency of the firm. Much of the calculation packet creation process did not require a working structural engineering knowledge. For standard jobs, an engineer made a duplicate calculation packet from a similar job and changed entries such as the client name or tracked numbers that vary from job to job throughout the entire document. We needed a more automated method.

The end goal was a series of "standard templates" that would greatly simplify and accelerate the creation of a calculation packet for a range of typical jobs. The template needed to be user friendly and able to auto-populate based on values input by an engineer.

Ideally, an engineer would input an entry only once with that information being filled in as applicable. This functionality would increase efficiency as engineers would no longer have to search the entire document for small but important changes. Additionally, the template needed to perform tedious calculations; allowing an engineer to input the needed design parameters for a project and have the resulting calculations returned with their values placed in the correct positions. This automation would increase the firm's overall efficiency. The situation presented here is the inspiration for this project.

Function Specifics and the Journey to Visual Basic for Applications

The finished product needed to recognize specific values, use them in calculations, and also display them in a written form. I pursued Microsoft Office Excel as it works very well for recognizing numbers and performing calculations. Unfortunately, Excel does not easily work with blocks of text or displaying number values within blocks of text. The ability to organize and customize paragraphs and spacing on pages, was necessary for the standard template as those things often change between jobs. For this reason, Office Word was chosen as the current method for generating deliverables. Each program discussed accomplishes half of the needs for the standard template, thus, I pursued using a combination of these two programs to create a standard, automated calculation packet.

I began by conducting some research to see if a program tying Excel and Word together already existed. I found that it did, however, there was only one option. This Office add-in program could do calculations in Excel, import chosen cell values into Word, and place the values in prescribed positions in the Word document. Unfortunately, this program required a subscription. I noticed that the subscription would put a substantial limit on its functionality and therefore decided it would not be worthwhile to invest in. When using this program, there was a finite number of values that could be pulled from Excel into Word and the number of times one could pull values was limited also. This would mean that a small revision in Excel leading to sending new numbers over to the report in Word, would use up one of the allotted data transfers. This system applied even to the highest paying tier subscription. The firm wanted the ability to import values to Word an unlimited amount of times so I set out to write my own version of this program. I had not seen the code used for that program and I don't know how they chose to code such an action, but seeing their program proved to me that my goal was possible.

The Microsoft Office suite has built-in custom coding language called Visual Basic for Applications (VBA). This language works like most other coding languages and allows the user to write codes that automate tedious tasks within their chosen Microsoft Office program. In addition to automating actions in their chosen Microsoft Office program, VBA allows the user to work between Office applications. This is feature I needed for the foundation of my code.

How this Code Works

The first step in creating this template was to make an Excel spreadsheet that organized/displayed all of the input data, performed the desired calculations, and organized/displayed the results of those calculations. For this paper, I have created a simplified example to help illustrate the inner workings of my code. Figure 14 shows data from Cal Poly on their Architectural Engineering First Year enrollment by year [34]. Figure

15 shows an example of a simple calculation Excel could perform for an engineer, in this case, it is calculating the average number of students in the ARCE program per year.

	A	B	C	D
1	ARCE Senior Project Example Spreadsheet			
2				
3	ARCE First Year Enrollment by Year			
4				
5		Year	Number of Students	
6		2015	60	
7		2016	72	
8		2017	97	
9		2018	83	
10		2019	91	
11		Average	80.6	
12				
13	Destination Word Document Name:			
14	ARCE Senior Project Example Word Doc			
15				

Figure 14: Example Excel Spreadsheet

	A	B	C	D
1	ARCE Senior Project Example Spreadsheet			
2				
3	ARCE First Year Enrollment by Year			
4				
5		Year	Number of Students	
6		2015	60	
7		2016	72	
8		2017	97	
9		2018	83	
10		2019	91	
11		Average	=AVERAGE(C6:C10)	
12				
13	Destination Word Document Name:			
14	ARCE Senior Project Example Word Doc			
15				

Figure 15: Example Excel Calculation

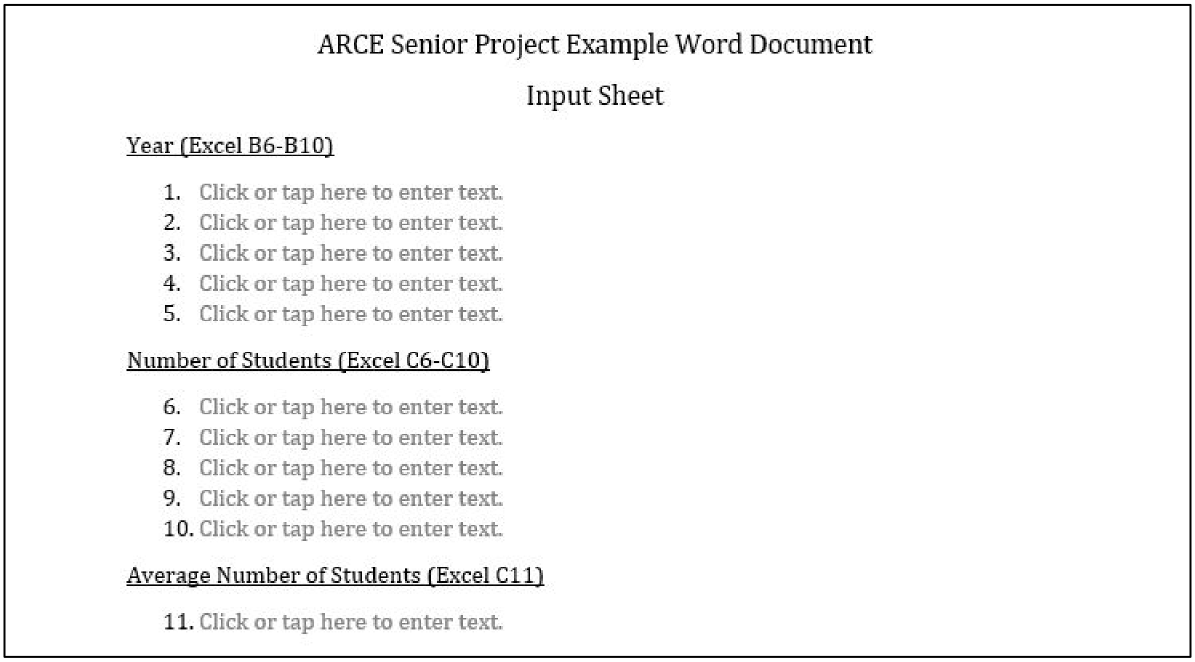
Once I had that spreadsheet, I began writing the portion of my VBA code that originated in Excel and imported values to Word. This portion runs from inside Excel, opens the desired Word Document (Figure 16), and places the chosen specific cell values into Word (Figure 17). Once in Word, the receiving report needed a place to house these values from Excel that would allow for referencing throughout the report. I settled on creating a few “Input sheets” in the beginning of the Word Document that are intended only for use by the code. These input sheets contained the same quantity of Content Controls as there were specific values being imported from Excel, for user ease, these Content Controls are numbered (Figure 18). A Content Control is essentially a section in the document that is separate from average text (Figure 19). When assigned a specific “Style” as a property, it can be referenced throughout the document by using the Style as an identifier (Figure 20). The Excel portion of the VBA code I wrote takes the chosen values from Excel and places them individually into the numbered Content Controls in Word (Figure 21).

```
Sub ExamplePushToWord()

 Dim wordApp As Word.Application
    Dim wdoc As Word.Document
    Dim r As Integer

    Set wordApp = CreateObject("word.application")
    Set wdoc = wordApp.Documents.Open(ThisWorkbook.Path & "/" & Range("A13").Value & ".docx")
    wordApp.Visible = True
```

Figure 16: VBA Code to Open the Word Document with the Title from Cell A13

```
'    The variables defined below determine the row Excel will export values from

    a = 6
    b = 6
    c = 11


'    The commands below will place the year into Word

    For i = 1 To 5

        wdoc.ContentControls(i).Range.Text = Sheets("Sheet1").Cells(a, 2)
        a = a + 1

    Next i


'    The commands below will place the number of students into Word

    For i = 6 To 10

        wdoc.ContentControls(i).Range.Text = Sheets("Sheet1").Cells(b, 3)
        b = b + 1

    Next i


'   The command below will place the average number of students into Word

        wdoc.ContentControls(11).Range.Text = Sheets("Sheet1").Cells(c, 3)
```

Figure 17: VBA Code to Place Year, Number of Students, and Average Number of Students into Word



ARCE Senior Project Example Word Document

Input Sheet

Year (Excel B6-B10)

1. Click or tap here to enter text.
2. Click or tap here to enter text.
3. Click or tap here to enter text.
4. Click or tap here to enter text.
5. Click or tap here to enter text.

Number of Students (Excel C6-C10)

6. Click or tap here to enter text.
7. Click or tap here to enter text.
8. Click or tap here to enter text.
9. Click or tap here to enter text.
10. Click or tap here to enter text.

Average Number of Students (Excel C11)

11. Click or tap here to enter text.

Figure 18: Example Word Document Input Sheet

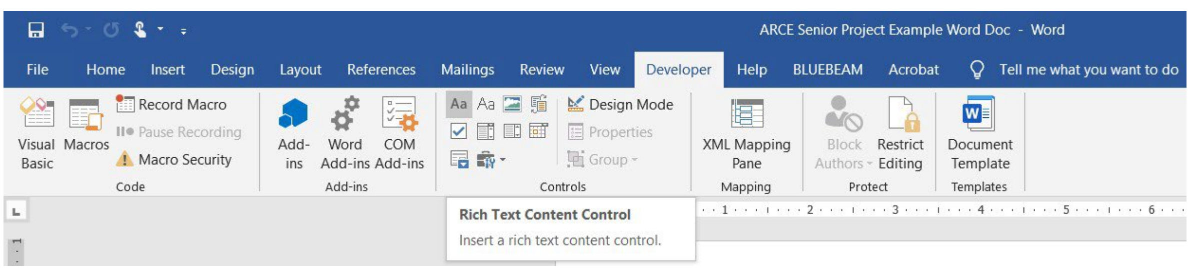


Figure 19: The Content Control Button

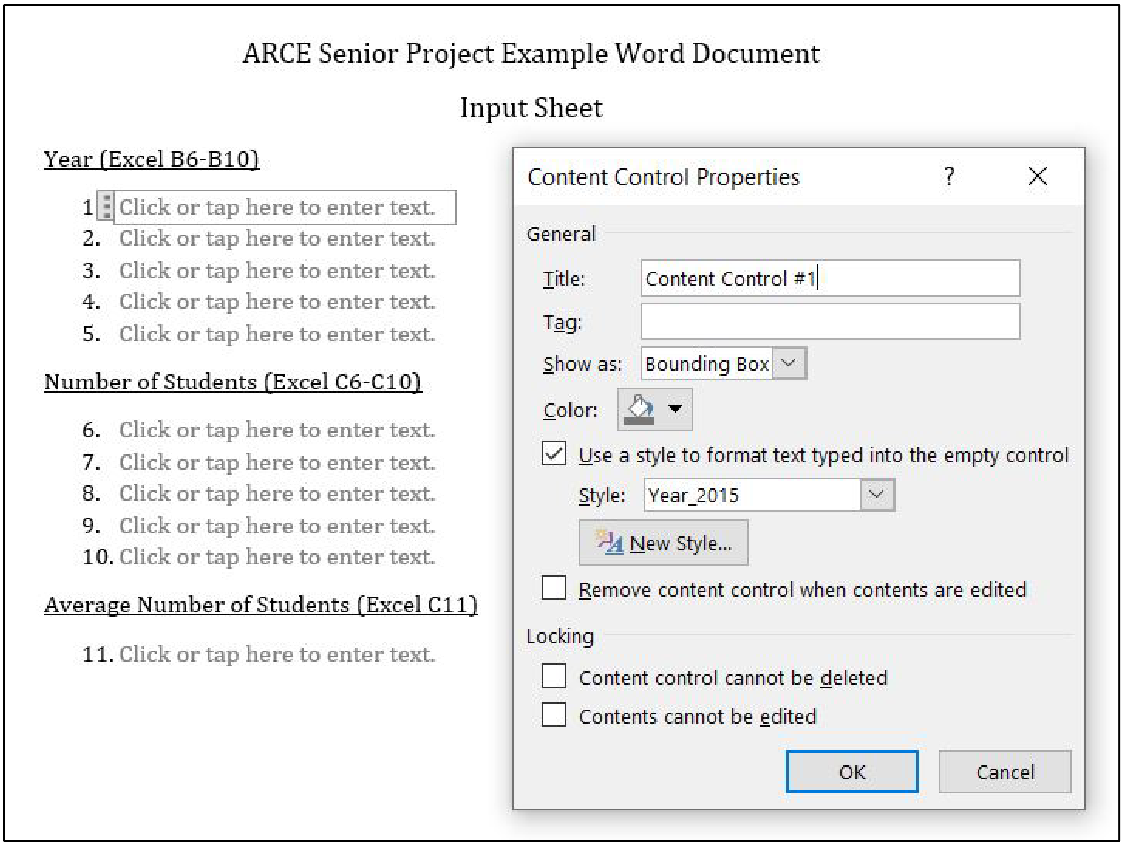


Figure 20: Content Control #1 Assigned the Style Name "Year_2015"

ARCE Senior Project Example Word Document

Input Sheet

Year (Excel B6-B10)

1. 2015
2. 2016
3. 2017
4. 2018
5. 2019

Number of Students (Excel C6-C10)

6. 60
7. 72
8. 97
9. 83
10. 91

Average Number of Students (Excel C11)

11. 80.6

Figure 21: Input Sheet with Excel Values Filled in via VBA

At this point, the goal I set out for was accomplished; I had a code that would allow an engineer to do tedious calculations in Excel and easily import those values into the correct positions in a preformulated report. Upon completion, I saw an opportunity to streamline this process even further. Once the Content Controls in Word were filled by Excel, they each needed to be labeled with their own unique identifier to enable referencing throughout the report. To individually label these would necessitate adding each individual Style name (the unique identifier) to the Word Style Library and then assigning each Style to the correct Content Control. Doing this by hand was not desirable for a multitude of reasons. As an example, I was the only employee present who knew how to do this but the goal of the template was to create a user-friendly program. Additionally, this was quite time consuming and the standard template was supposed to increase efficiency in the firm. Further, the amount of individual values imported to Word increased with the complexity of the calculation being performed thus increasing the amount of Styles to be added and assigned. As such, I chose to write another VBA code in Word that would automate this action.

The VBA Word code I wrote pulled additional values from Excel and used those as the Style names. I set up another page in my Excel spreadsheet that contained all of the desired style names (Figure 22) and then had Word pull those cell values and use them as the names of each new Style. Once the Styles were added to the Style Library (Figure 23), the code needed the ability to assign the correct Style name to the correct Content Control. To do this, the names are typed into Excel in the order in which the Content Controls appear and then the VBA Word code assigns the names sequentially.

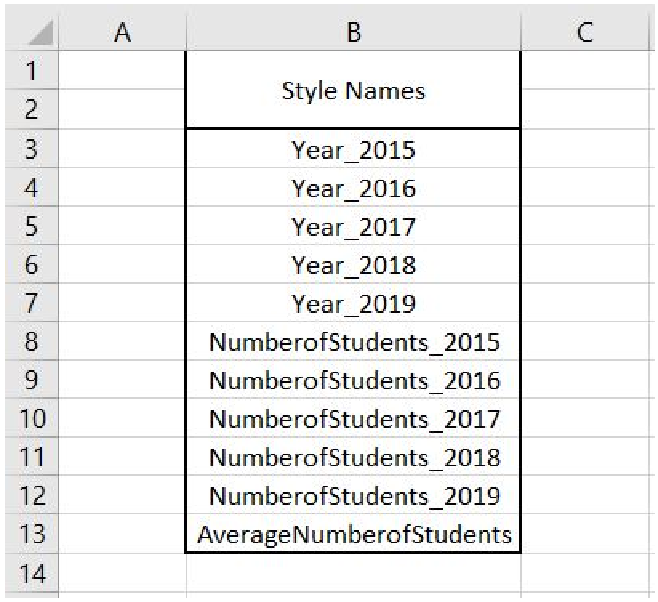


Figure 22: Desired Style Names Listed Sequentially in Excel

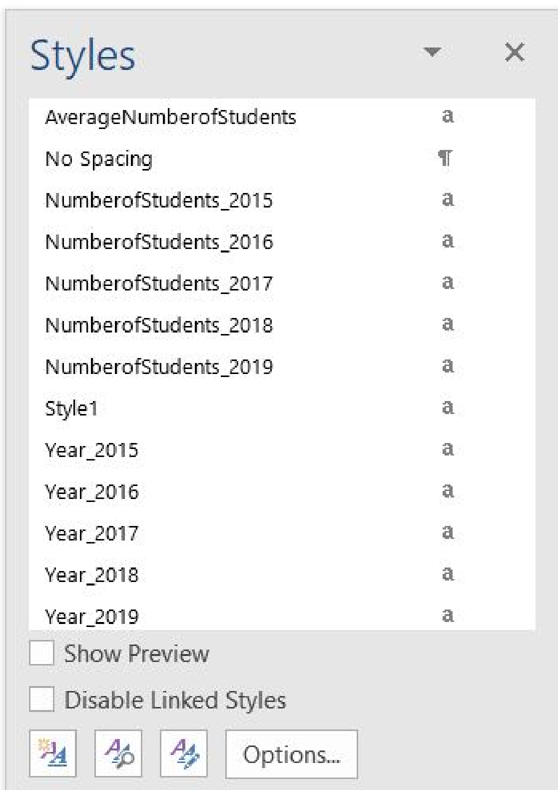


Figure 23: Word Style Library with Custom Styles Imported

After both the Word and Excel VBA codes have been executed, the resulting Word document contains all of the desired values from Excel and has each one uniquely labeled for easy reference throughout the report. To reference these values in the report, a field can be inserted anywhere into the document (Figure 24). This field is set to reference a specific Style and the number contained in the associated Content Control is placed into the desired spot in the document (Figure 25). Placing the correct fields in the correct locations throughout the report is done by hand as it requires the knowledge of performing the calculations without automation. This step is only necessary once in the lifetime of the document because once the document is set up with the correct fields appropriately labelled, they will be auto-populated with whatever value is in the corresponding Content Control (Figure 26).

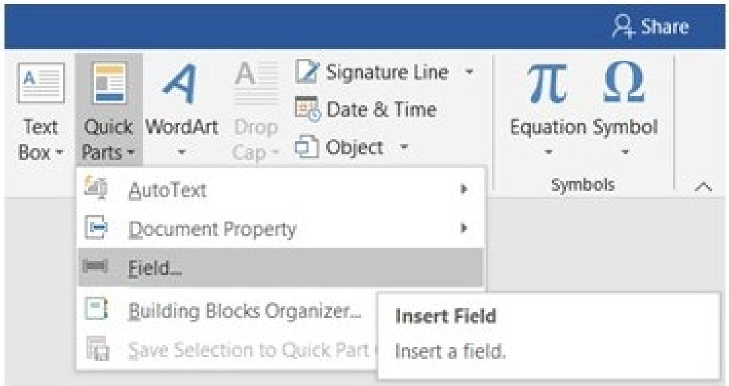


Figure 24: Insert a Field into Word

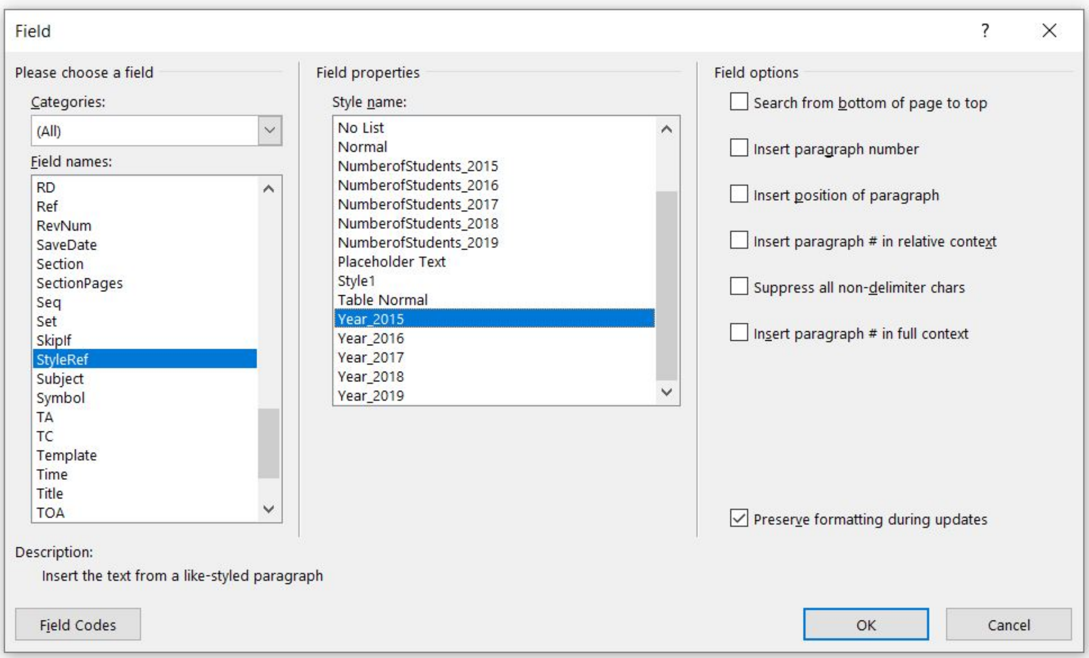


Figure 25: Insert a Field Using the StyleRef Function and Assigning the Correct Style Name

ARCE Senior Project Example Word Document

Input Sheet

Year (Excel B6-B10)

1. 2015
2. 2016
3. 2017
4. 2018
5. 2019

Number of Students (Excel C6-C10)

6. 60
7. 72
8. 97
9. 83
10. 91

Average Number of Students (Excel C11)

11. 80.6

This data shows the amount of first year students enrolled in the ARCE program in the past 5 years. The years that we polled were 2015, 2016, 2017, 2018, and 2019. These years all had similar amounts of enrolled students, those being 60, 72, 97, 83, and 91 respectively. The average number of students over the selected years was 80.6.

Figure 26: A Finished Paragraph with Values from Excel Referenced, Word Hightlights Fields Using Light Gray, Shown Here

Once all of the fields have been placed and assigned, the document can be changed for any project and it becomes a malleable, standard template for all jobs that fit the calculations of that packet. With this new system, an engineer would have minimal steps to create a full calculation packet report. These consist of opening the Excel file paired to the standard template of their choosing, changing the input values to match the new project, letting Excel perform the calculations, then running the Excel VBA macro code. The VBA macro imports the correct values from Excel into the paired Word document and references them in the correct places, assuming the project is similar in type to the chosen template. This greatly decreases the tedious work an engineer needs to do and thus accomplishes the goal my boss had envisioned for an automated calculation packet.

Conclusions

This project was inspired by an internship I had that focused on mounting solar panels to existing buildings. The structural knowledge I gained through my coursework at Cal Poly provided a great foundation for my success in this field. I analyzed existing buildings to determine member capacity for additional loads (solar panels and accompanying equipment for future installation). I pursued this project to gain a broader knowledge on the solar industry; my internship only covered a portion of the field. Through this project, I sharpened my skills in independent research. The knowledge gained on solar power basics and its impacts was obtained via reading online articles, speaking with qualified specialists, and personally working in the field. I read many online sources and synthesized the applicable information to create a comprehensive image of the field. To complete the Visual Basic portion of my project, I applied skills taught in my undergraduate classes on MatLab, tested hypotheses through trial and error, and learned new code commands through online articles and forums. The knowledge I gained on the structural calculations associated with a solar system installation was gleaned from my internship. At work, I looked for guidance in previous installations of a similar nature to what I was working on, I also researched issues I came across in the applicable buildings codes, and I referred to my boss and coworkers for additional questions.

Lessons that I learned through this project include the relationship between school and professional work and the importance of time management in long-term projects. As this project was built from topics covered in my internship, I worked with my boss to understand how to present work material in a way that would be appropriate for school – this included handling of proprietary information in a project meant for publication. This project has been created over a course of many months, and because the timeframe felt large, I had to work with my faculty project advisor to develop strategies for accomplishing the project in a timely manner. We settled on goal setting through schedules and the necessity of a weekly meeting for accountability. Looking back, I feel that I applied the Cal Poly "Learn by Doing" mindset to this project by working directly in the field to gain my own experiences and learning how to create a project of this caliber this by doing it myself.

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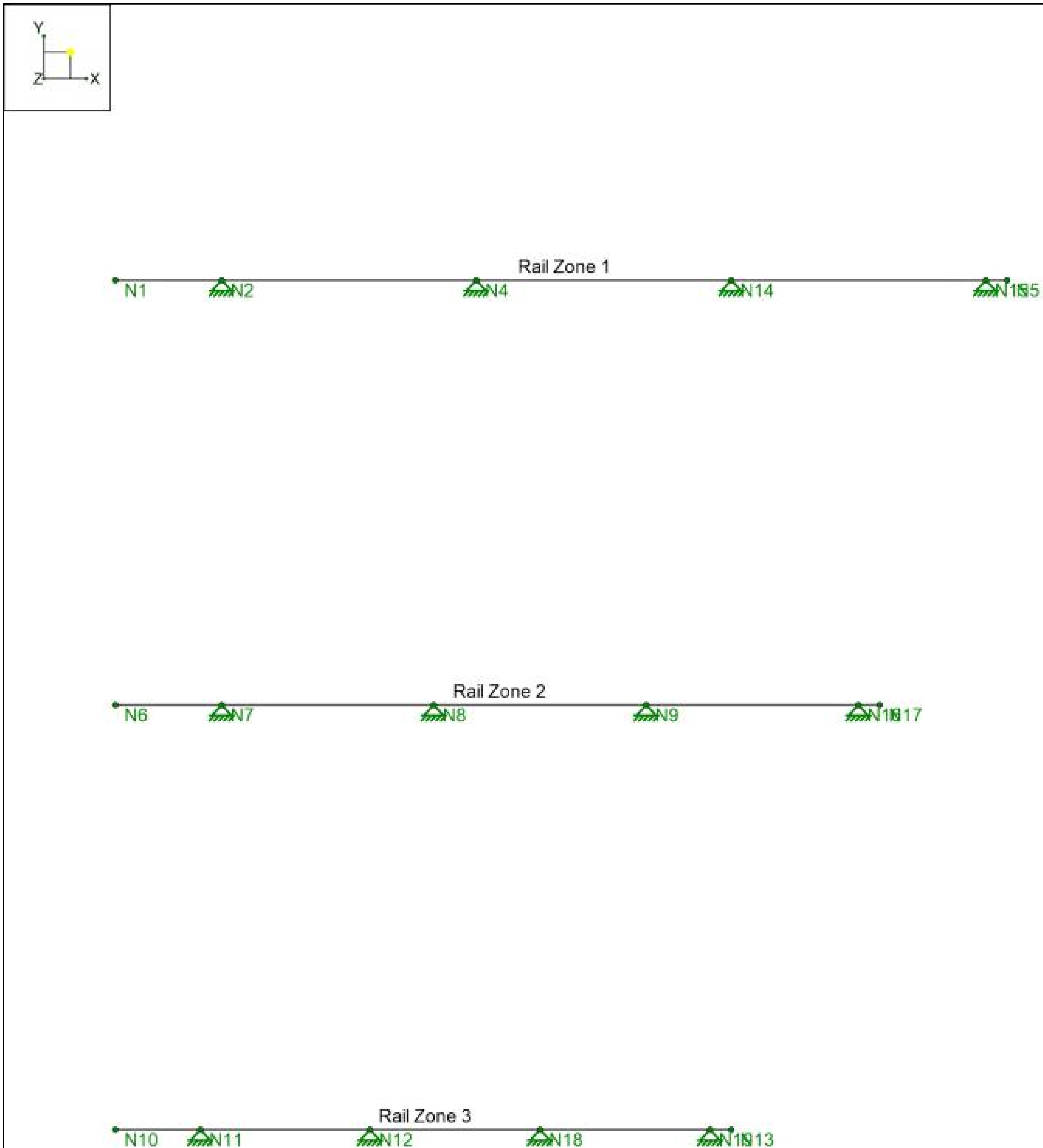
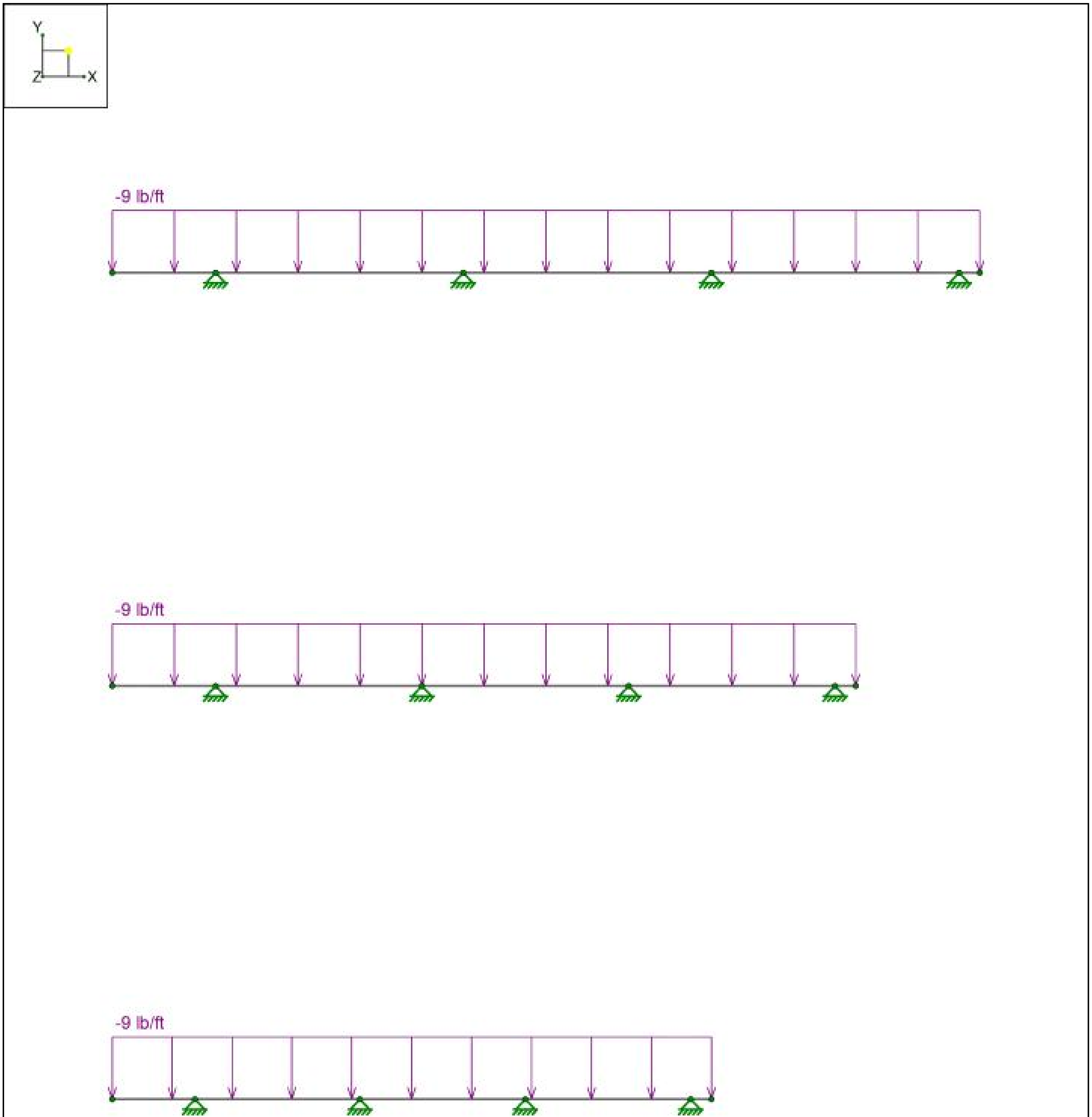
Appendix A

Solar Module Racking Rail RISA Graphics and Report

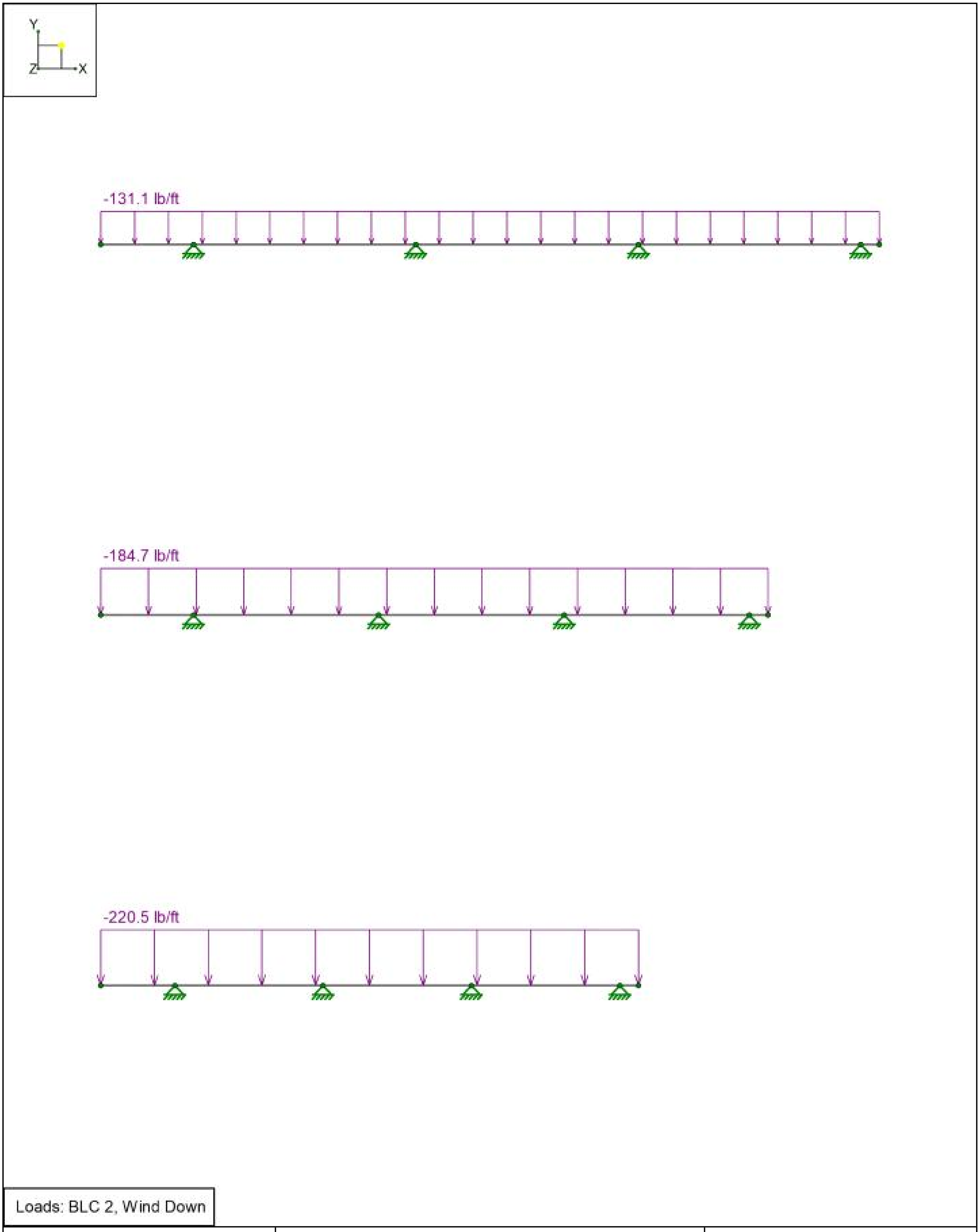


	ARCE Senior Project (Rails)	SK-1
ROK		
		Senior Project (Rails).r3d



Loads: BLC 1, Dead

	ARCE Senior Project (Rails)	SK-2
ROK		
		Senior Project (Rails).r3d



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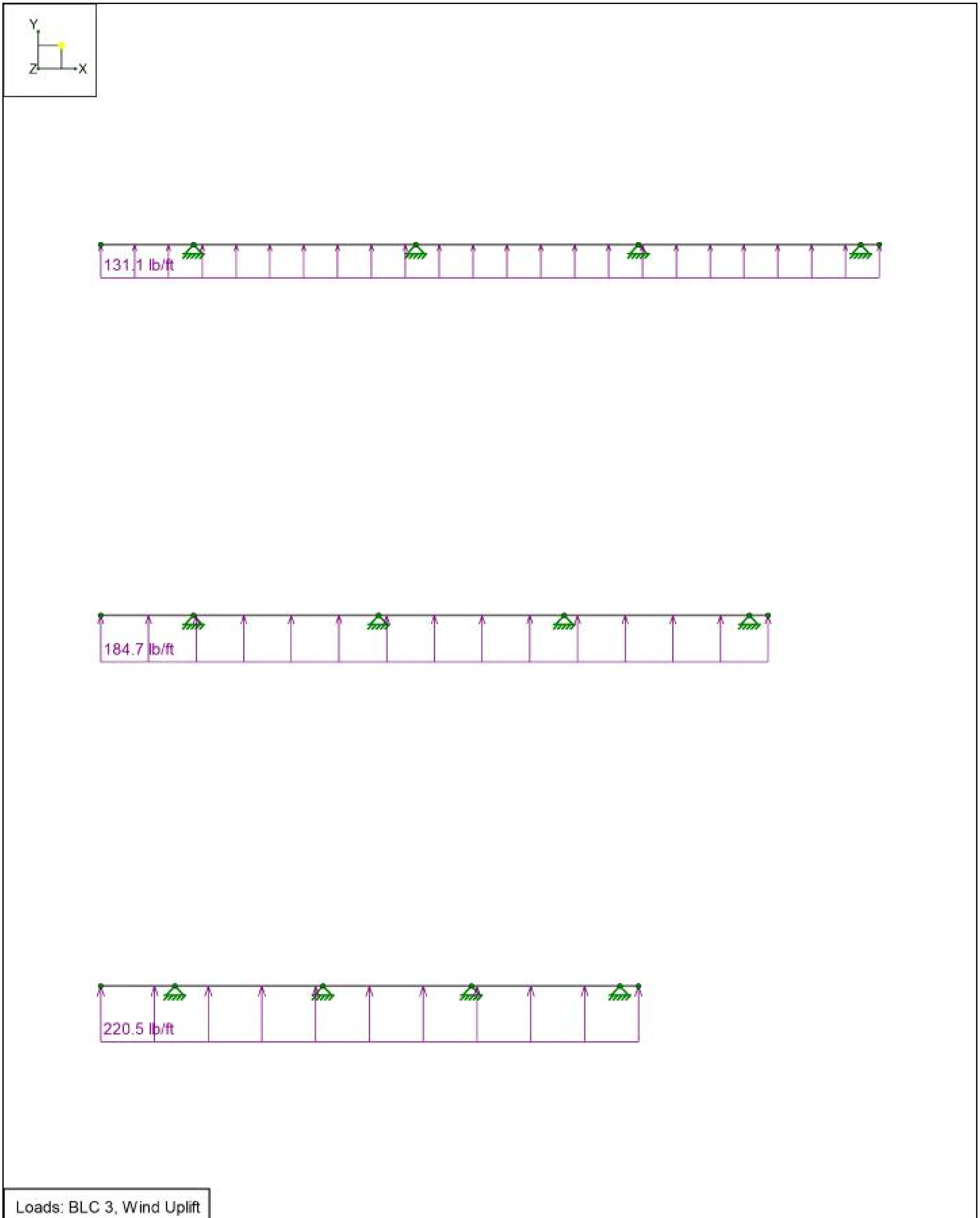
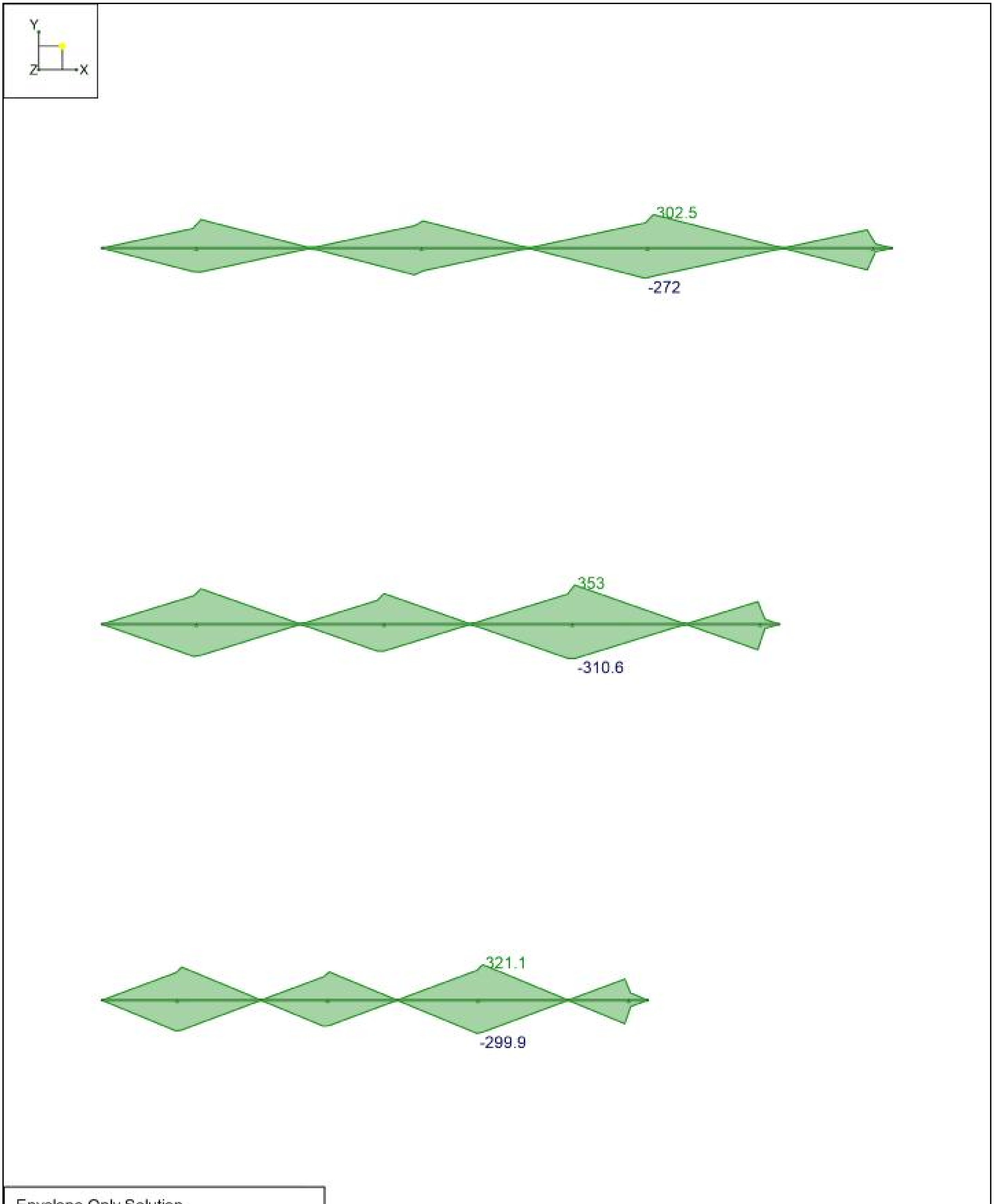
ROK		
		Senior Project (Rails).r3d

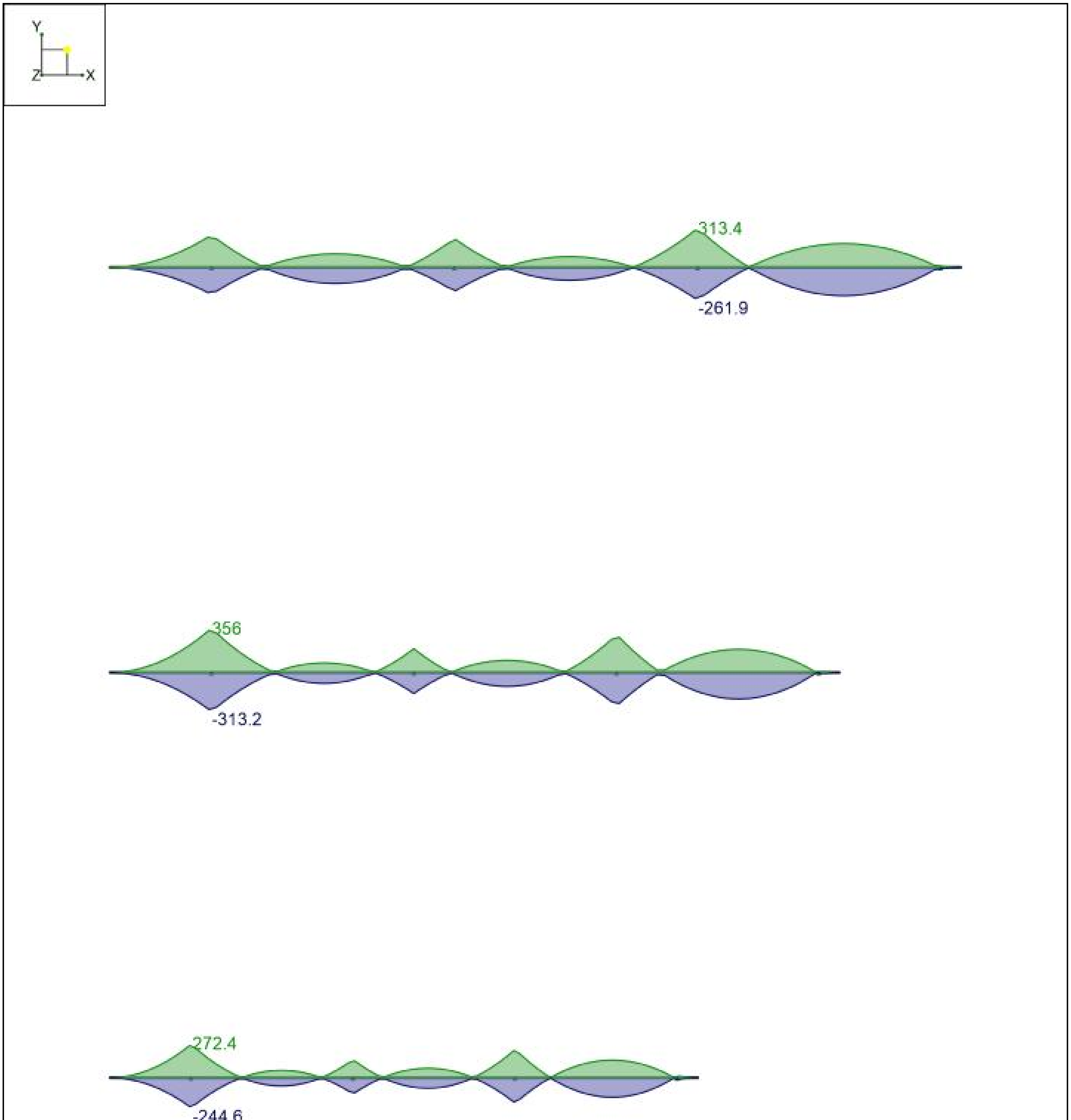


	ARCE Senior Project (Rails)	SK-4
ROK		
		Senior Project (Rails).r3d



Envelope Only Solution
Member y Shear Forces (lbs) (Enveloped)

	ARCE Senior Project (Rails)	SK-5
ROK		
		Senior Project (Rails).r3d



Envelope Only Solution
Member z Bending Moments (lb-ft) (Enveloped)

	ARCE Senior Project (Rails)	SK-6
ROK		
		Senior Project (Rails).r3d

Basic Load Cases

	BLC Description	Category	Distributed
1	Dead	DL	3
2	Wind Down	WL	3
3	Wind Uplift	WL	3

Load Combinations

	Description	Solve	PDelta	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
1	ASCE ASD 1	Yes	Y	DL	1						
2	ASCE ASD 2	Yes	Y	DL	1	LL	1	LLS	1		
3	ASCE ASD 5 (a)	Yes	Y	DL	1	2	0.6				
4	ASCE ASD 5 (a)	Yes	Y	DL	1	3	0.6				
5	ASCE ASD 6 (a)	Yes	Y	DL	1	2	0.45	LL	0.75	LLS	0.75
6	ASCE ASD 6 (a)	Yes	Y	DL	1	3	0.45	LL	0.75	LLS	0.75
7	ASCE ASD 7	Yes	Y	DL	0.6	2	0.6				
8	ASCE ASD 7	Yes	Y	DL	0.6	3	0.6				

Member Distributed Loads

	Member Label	Direction	Start Magnitude [lb/ft, F, psf]	End Magnitude [lb/ft, F, psf]	Start Location [(ft, %)]	End Location [(ft, %)]	Inactive [(lb, lb-ft), (in, rad), (lb*s²/ft, lb*s²*ft)]
1	Rail Zone 1	Y	-9	-9	0	%100	Active
2	Rail Zone 2	Y	-9	-9	0	%100	Active
3	Rail Zone 3	Y	-9	-9	0	%100	Active

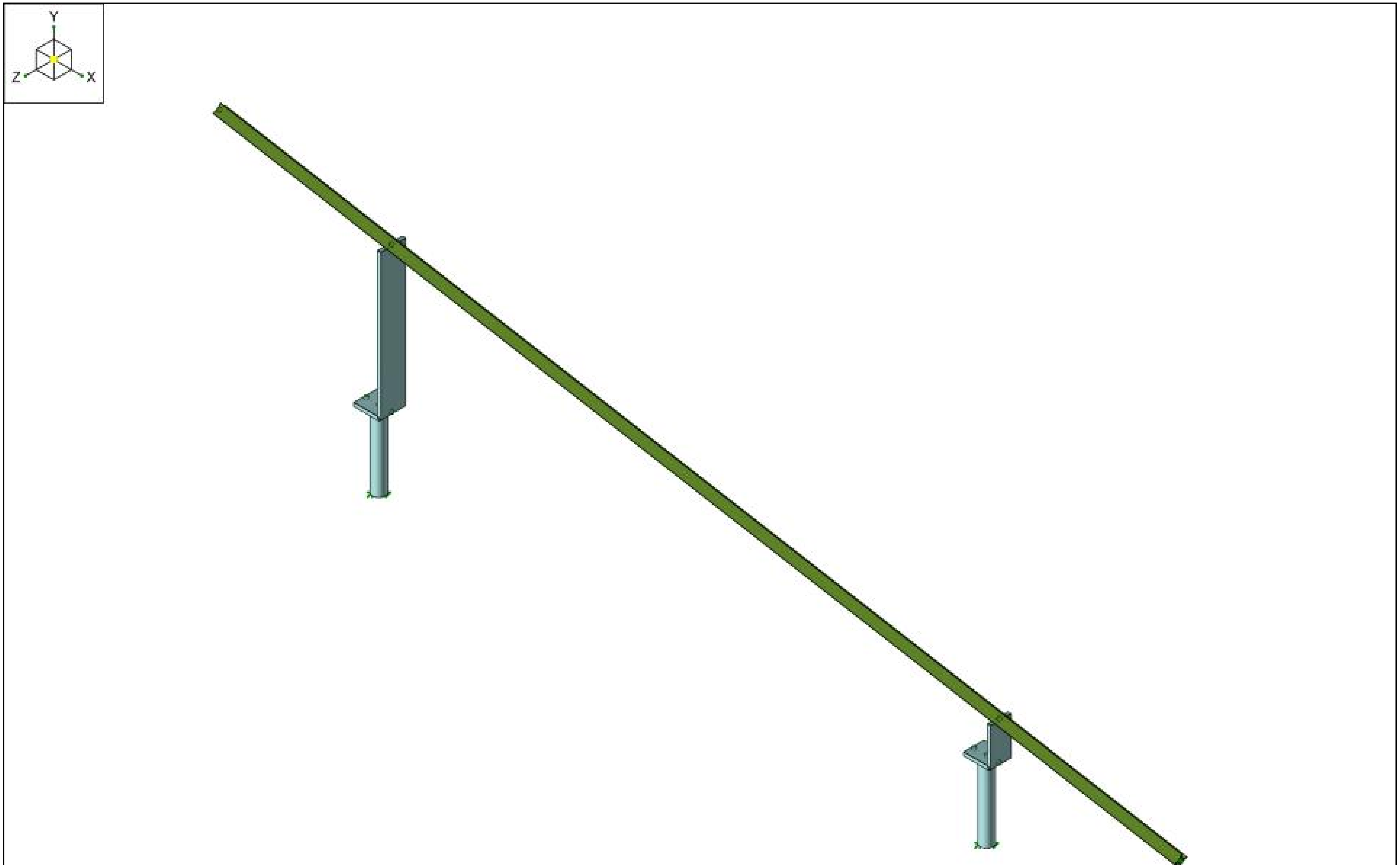
Member Distributed Loads

	Member Label	Direction	Start Magnitude [lb/ft, F, psf]	End Magnitude [lb/ft, F, psf]	Start Location [(ft, %)]	End Location [(ft, %)]	Inactive [(lb, lb-ft), (in, rad), (lb*s²/ft, lb*s²*ft)]
1	Rail Zone 1	Y	-131.1	-131.1	0	%100	Active
2	Rail Zone 2	Y	-184.7	-184.7	0	%100	Active
3	Rail Zone 3	Y	-220.5	-220.5	0	%100	Active

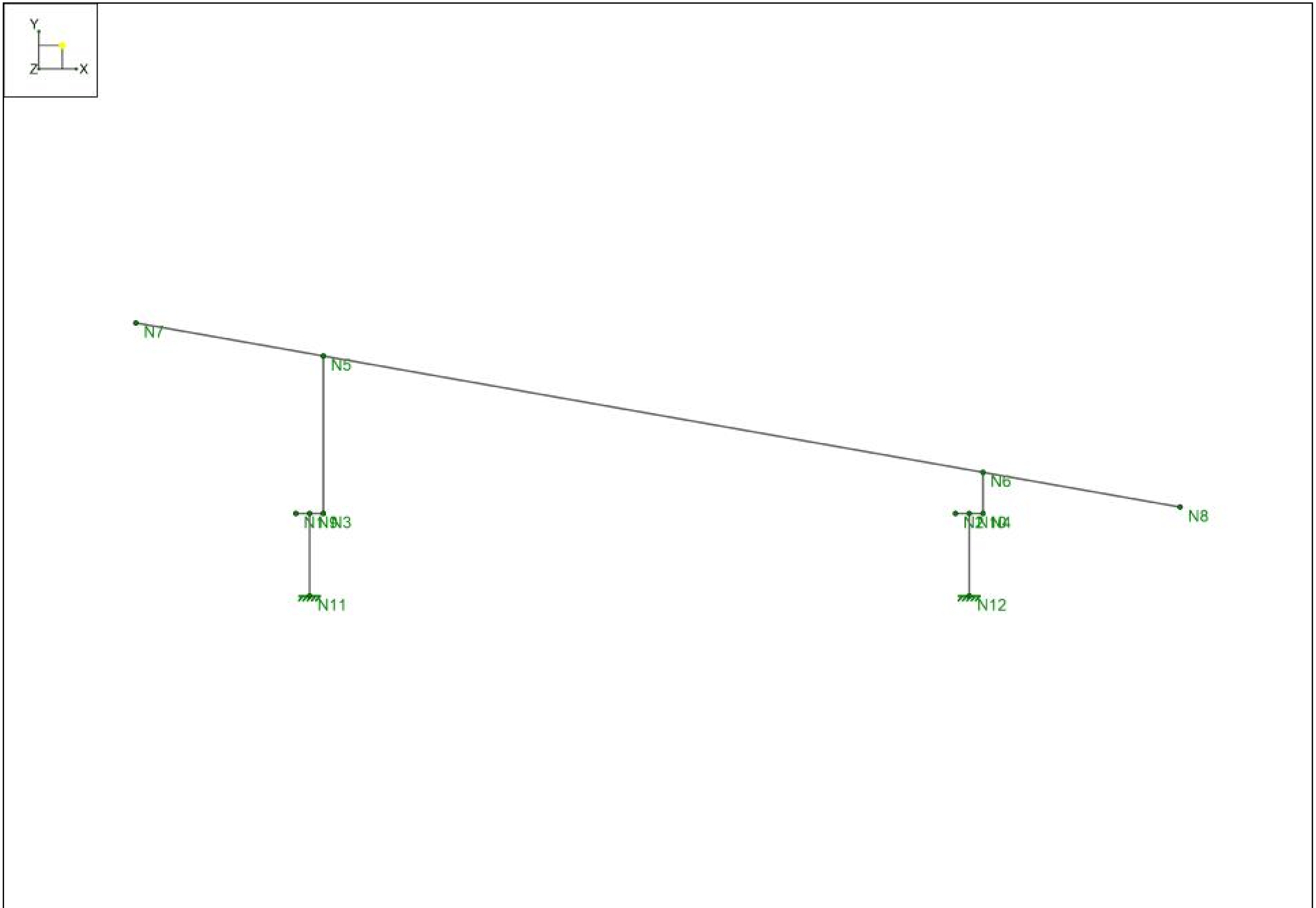
Member Distributed Loads

	Member Label	Direction	Start Magnitude [lb/ft, F, psf]	End Magnitude [lb/ft, F, psf]	Start Location [(ft, %)]	End Location [(ft, %)]	Inactive [(lb, lb-ft), (in, rad), (lb*s²/ft, lb*s²*ft)]
1	Rail Zone 1	Y	131.1	131.1	0	%100	Active
2	Rail Zone 2	Y	184.7	184.7	0	%100	Active
3	Rail Zone 3	Y	220.5	220.5	0	%100	Active

Solar Module Racking Tilt-Leg System RISA Graphics and Report



	ARCE Senior Project (Tilt Leg System)	SK-1
		Senior Project (Tilt Leg System).r3d



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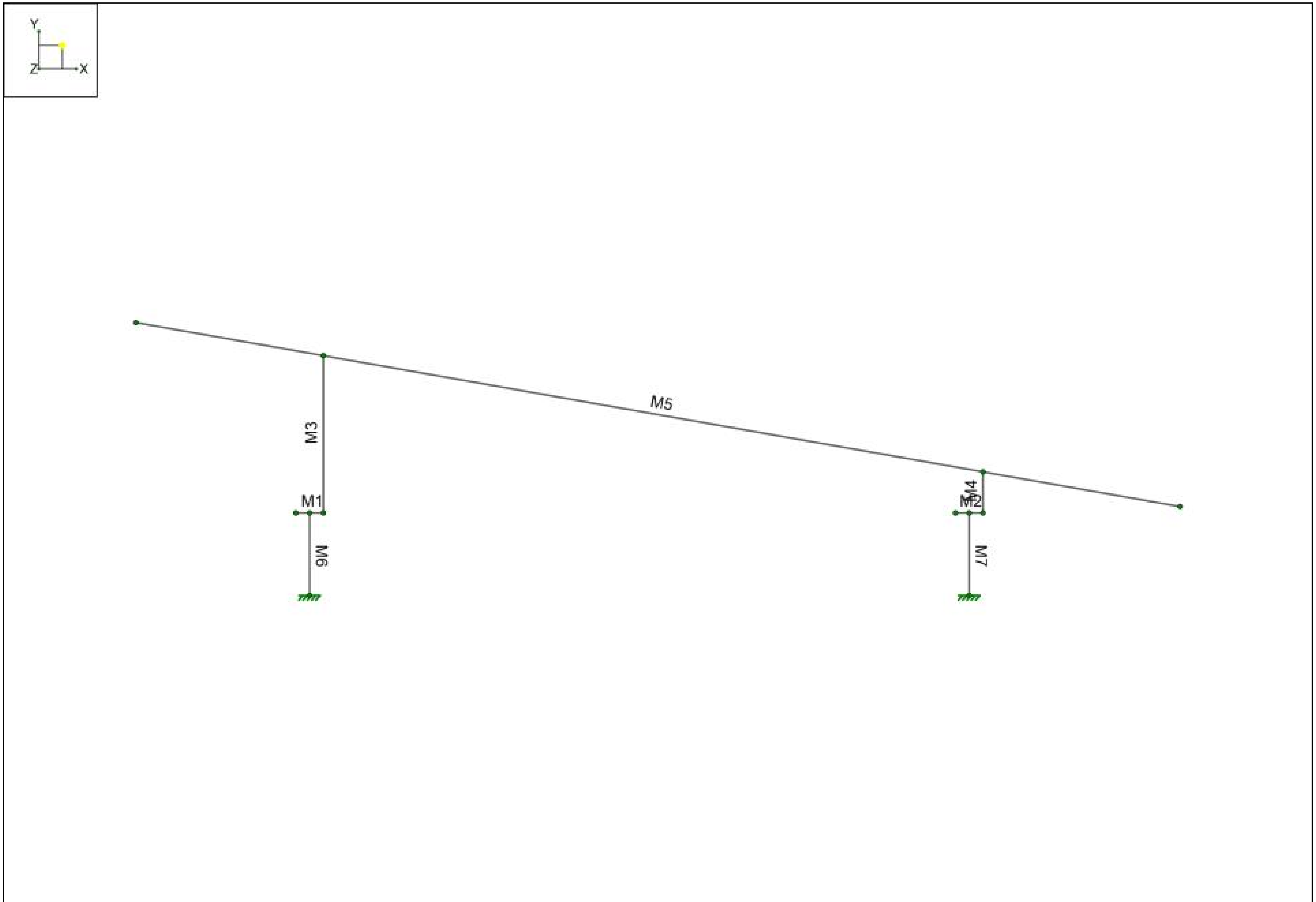
		Senior Project (Tilt Leg System).r3d



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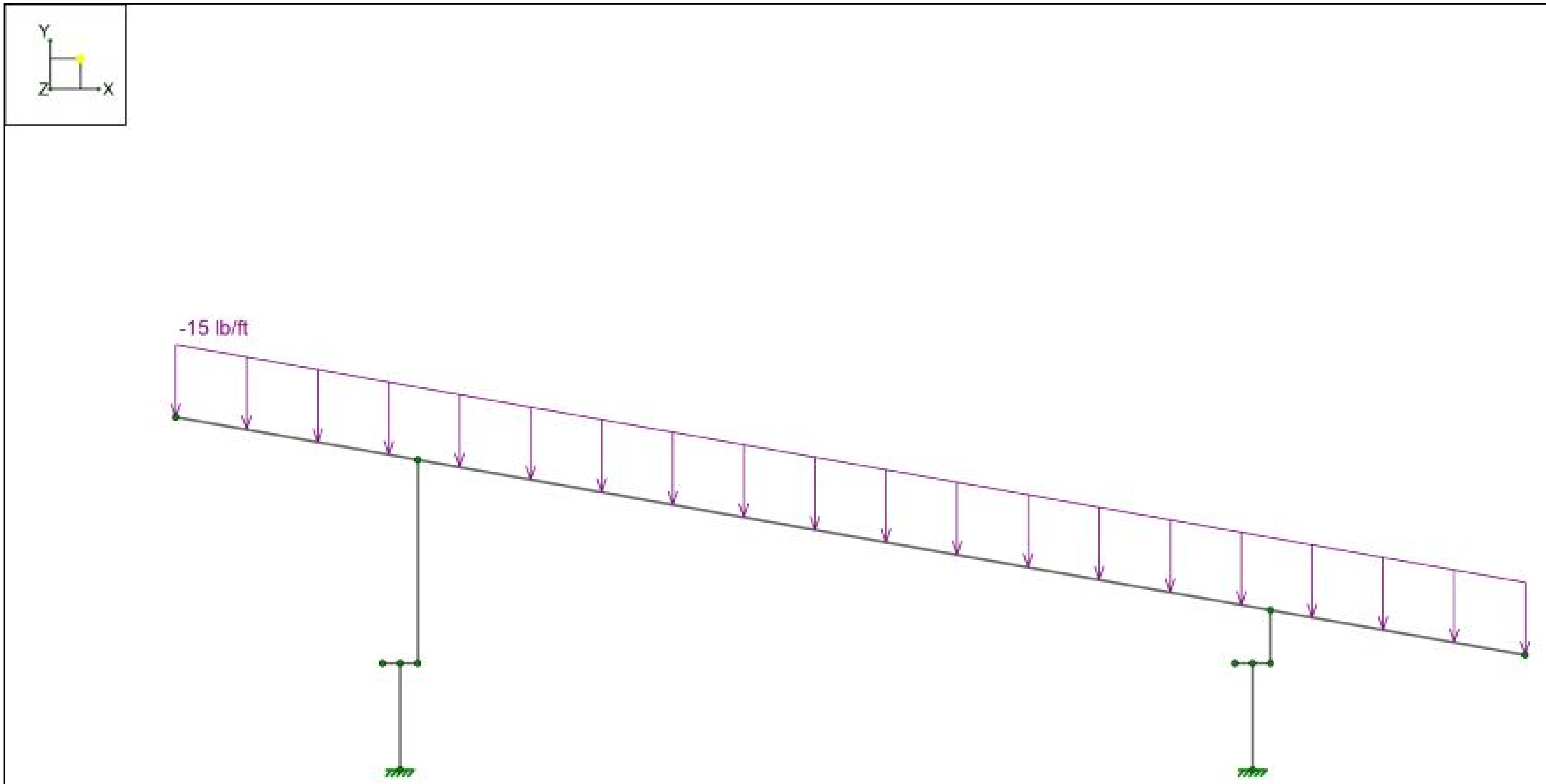
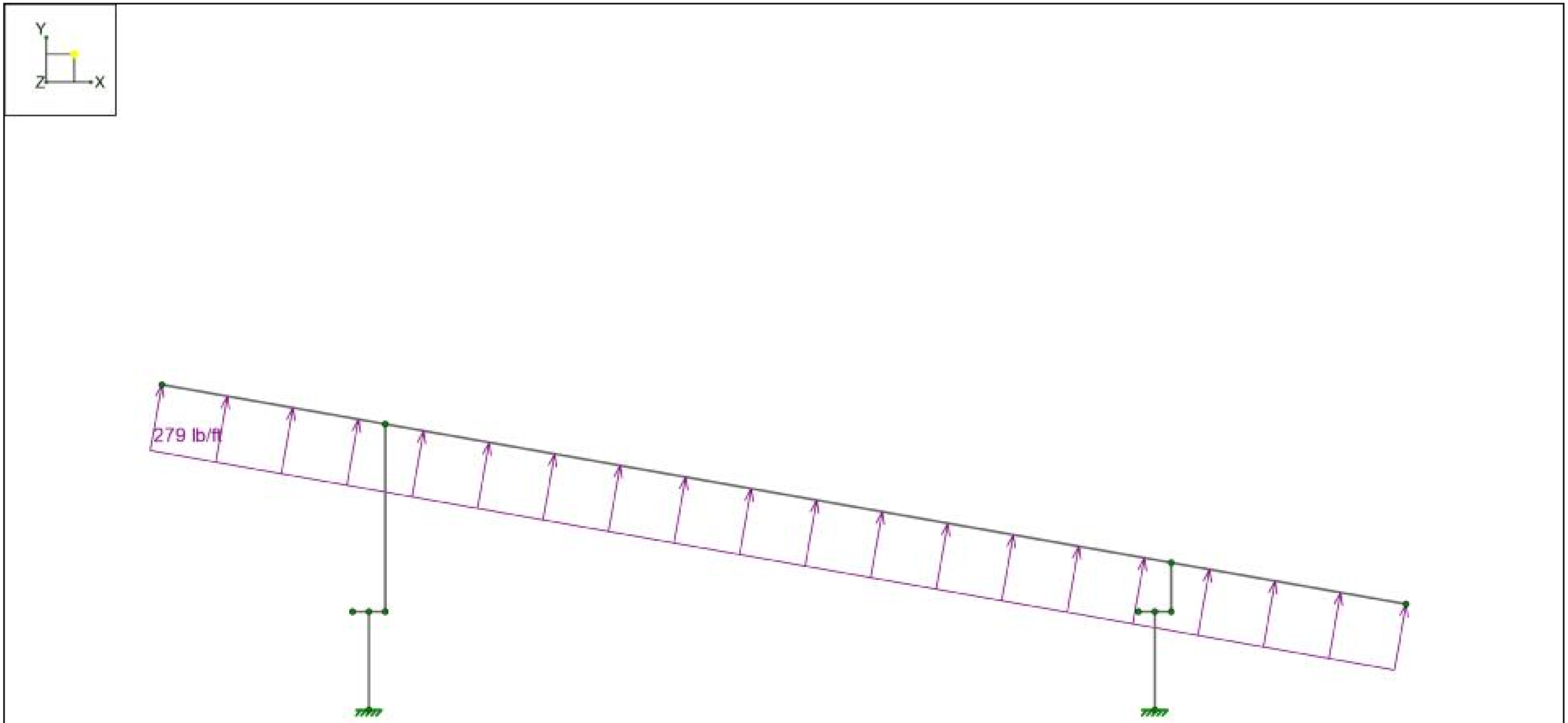
		Senior Project (Tilt Leg System).r3d



Loads: BLC 1, Dead

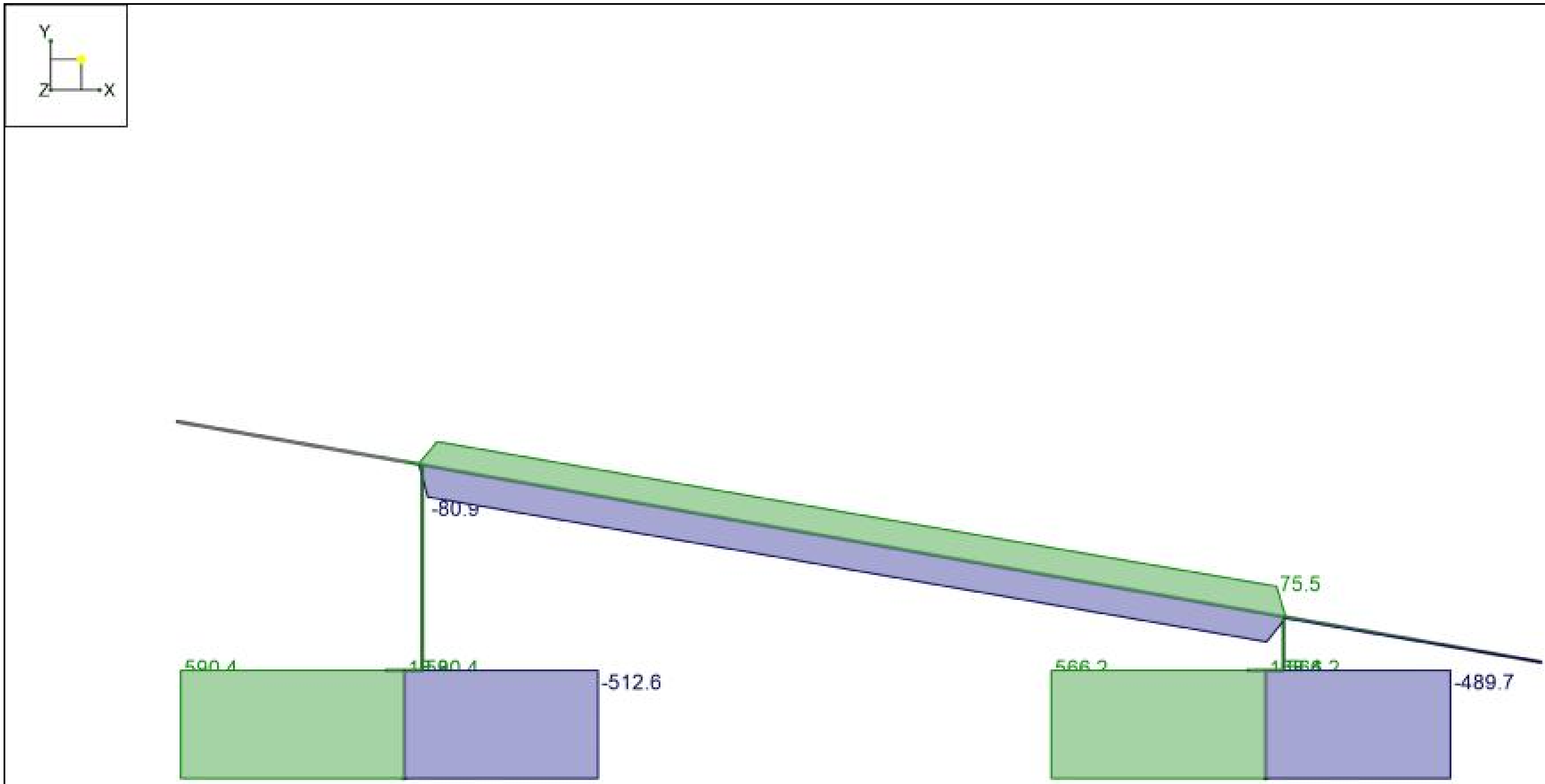
	ARCE Senior Project (Tilt Leg System)	SK-4
		Senior Project (Tilt Leg System).r3d



Loads: BLC 2, Wind Uplift

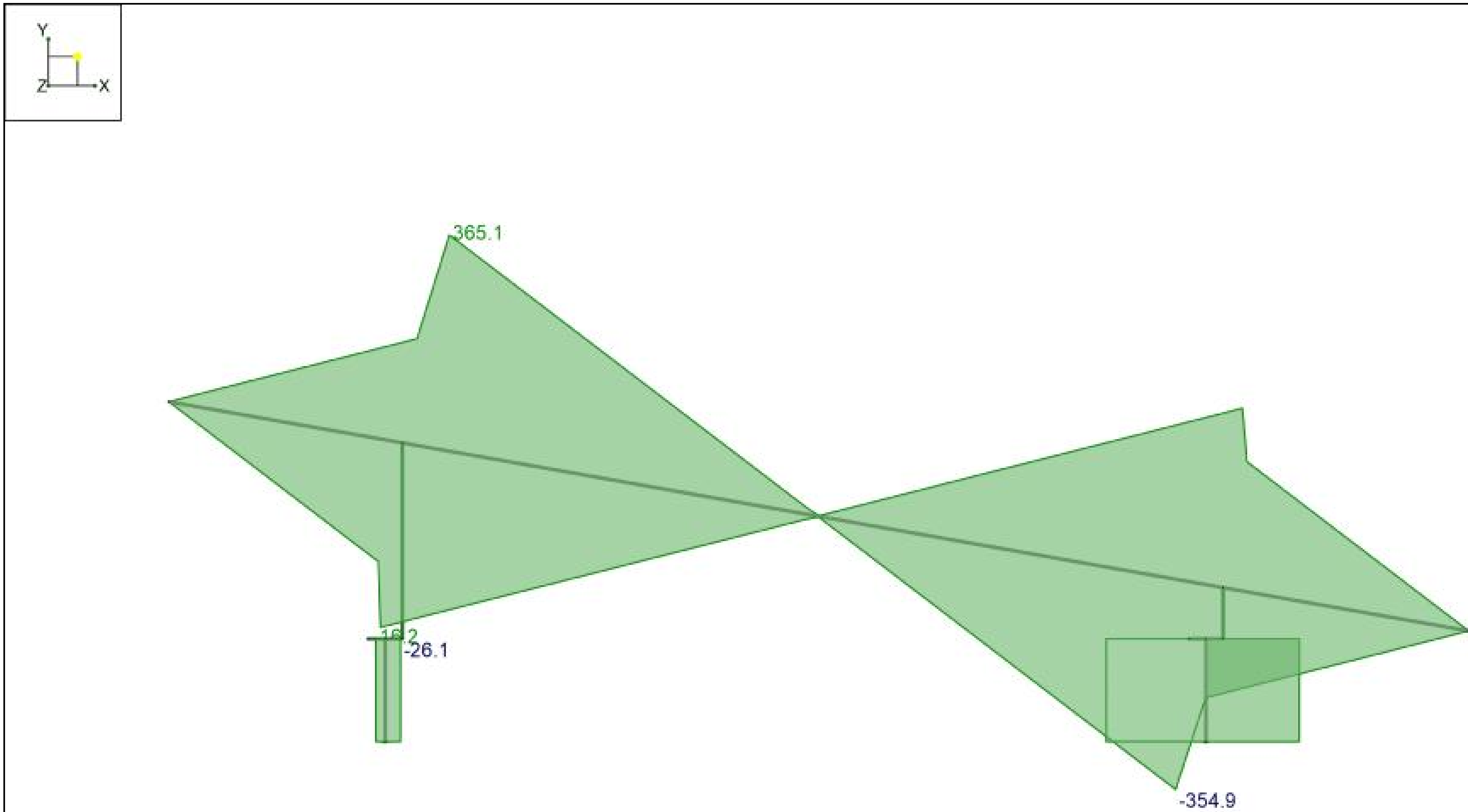
	ARCE Senior Project (Tilt Leg System)	SK-5
		Senior Project (Tilt Leg System).r3d

	ARCE Senior Project (Tilt Leg System)	SK-6
		Senior Project (Tilt Leg System).r3d



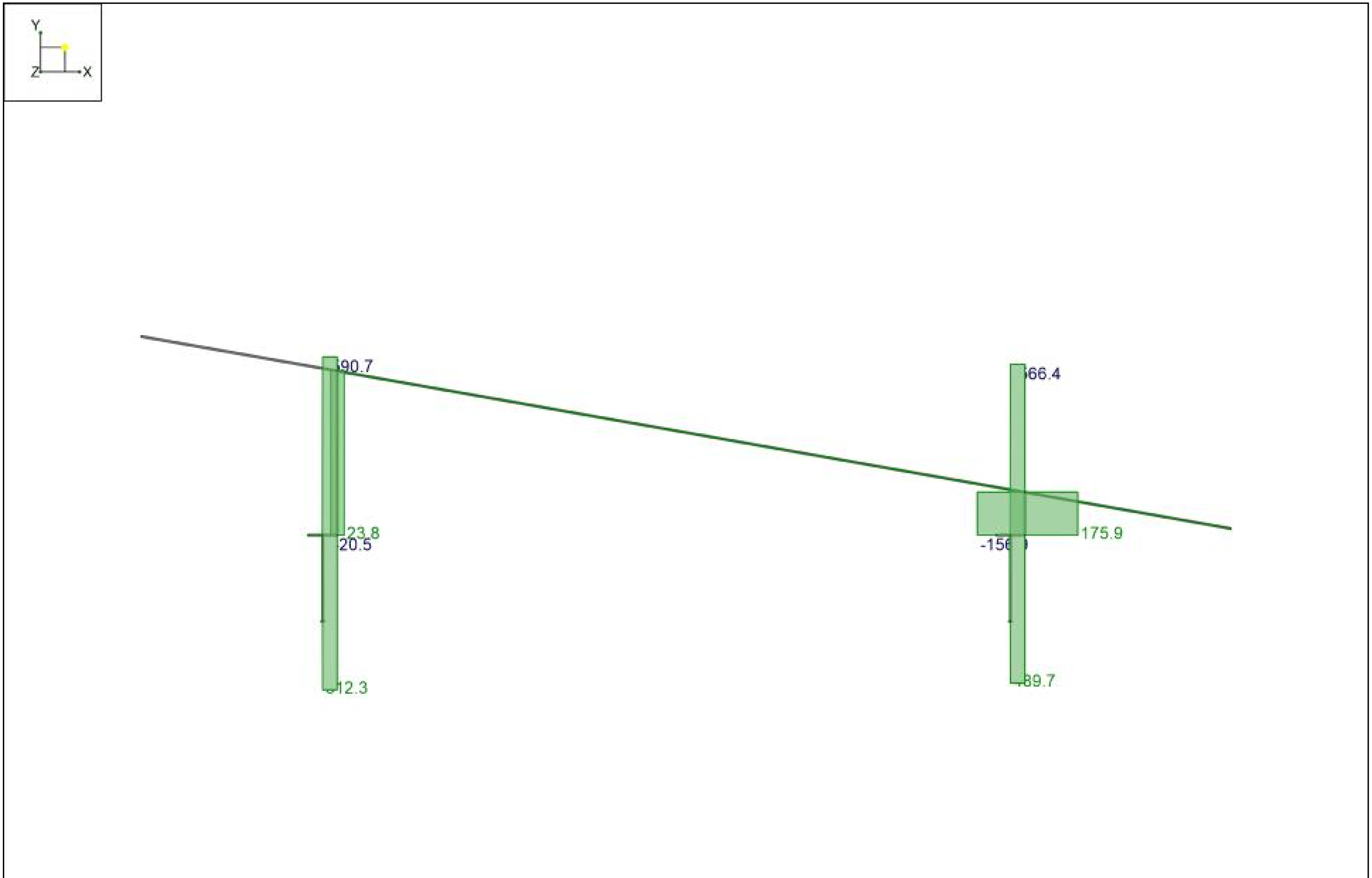
Envelope Only Solution
Member Axial Forces (lbs) (Enveloped)

	ARCE Senior Project (Tilt Leg System)	SK-7
		Senior Project (Tilt Leg System).r3d



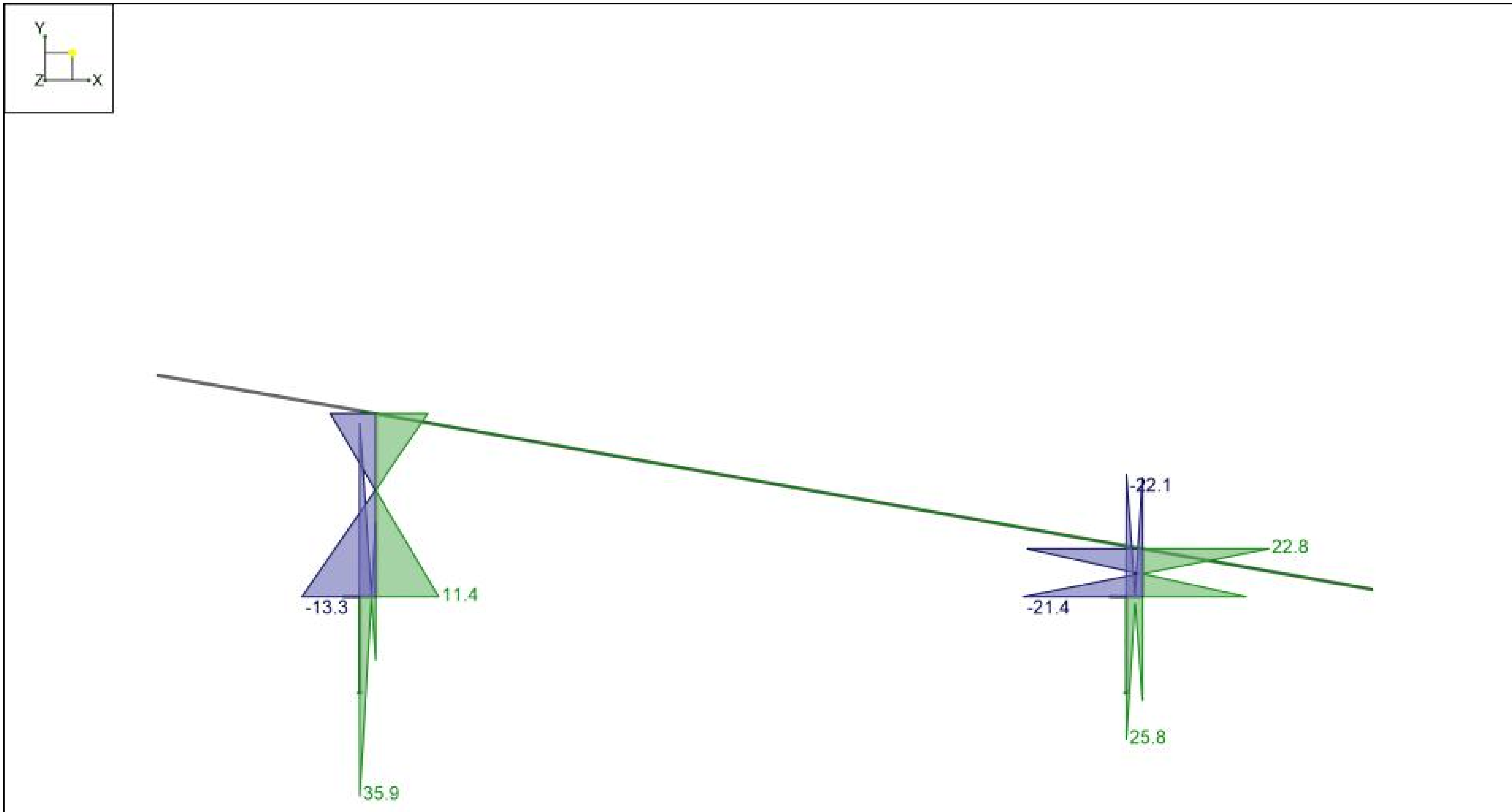
Envelope Only Solution
Member y Shear Forces (lbs) (Enveloped)

	ARCE Senior Project (Tilt Leg System)	SK-8
		Senior Project (Tilt Leg System).r3d



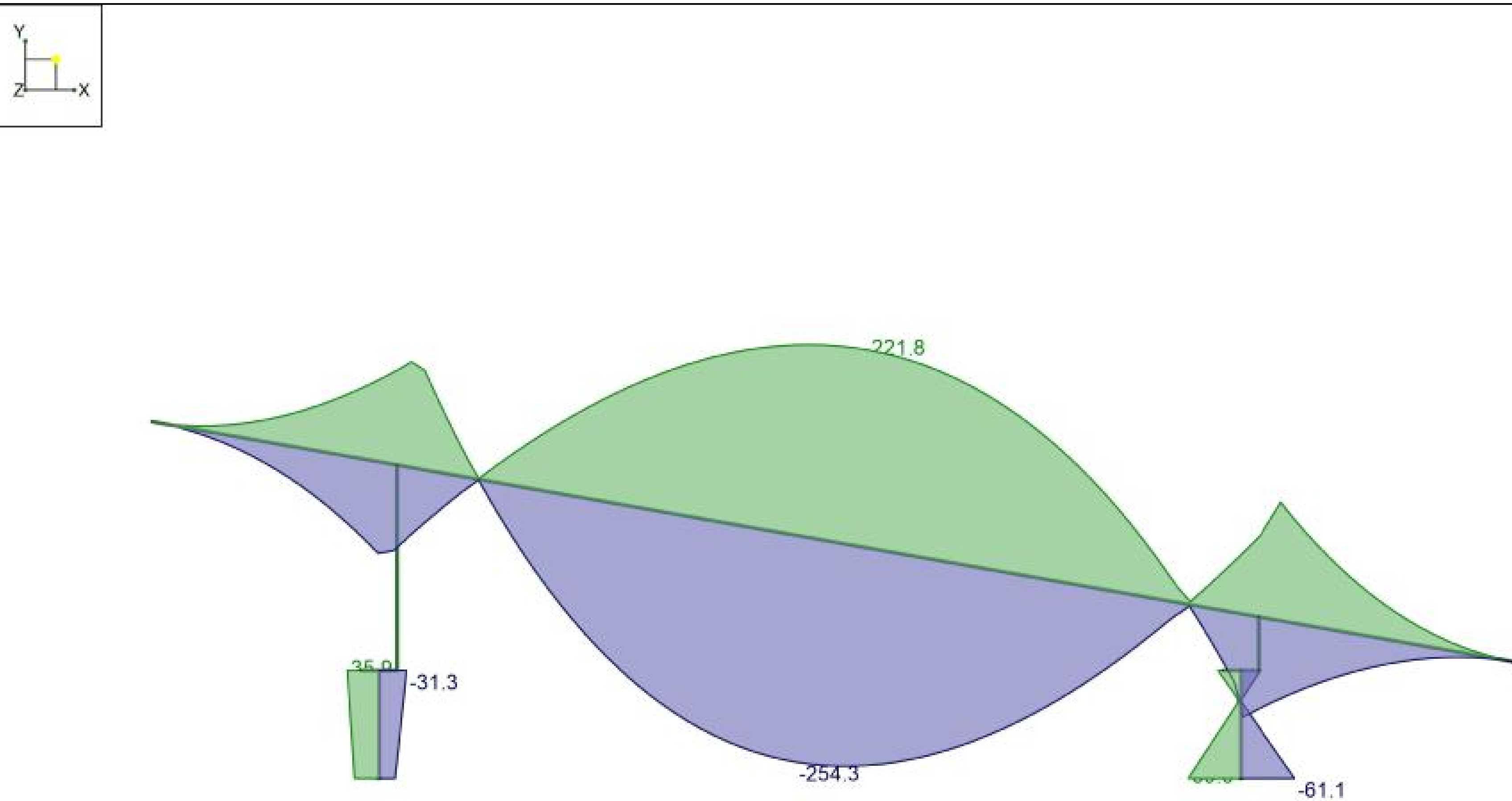
Envelope Only Solution
Member z Shear Forces (lbs) (Enveloped)

	ARCE Senior Project (Tilt Leg System)	SK-9
		Senior Project (Tilt Leg System).r3d



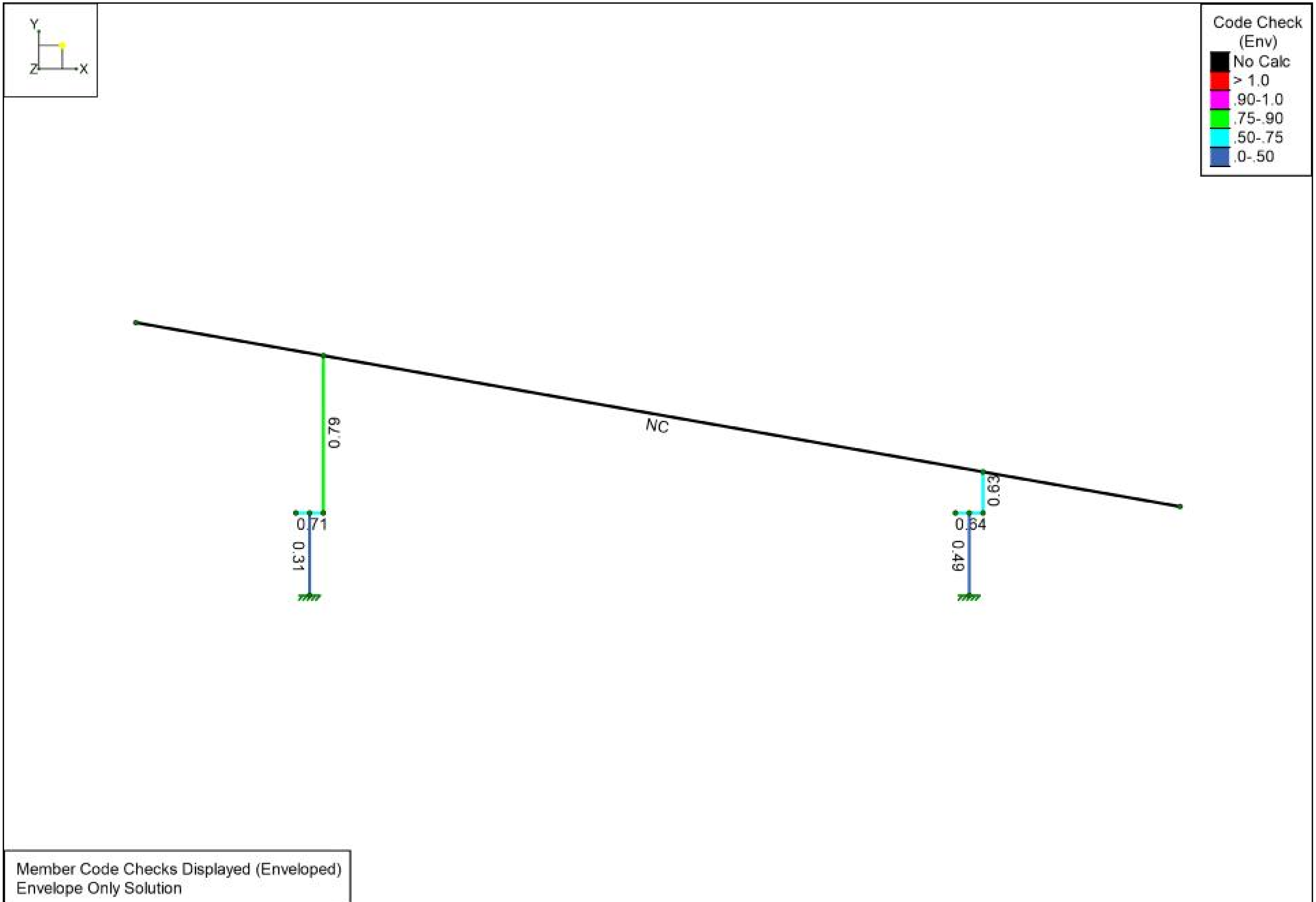
Envelope Only Solution
Member y Bending Moments (lb-ft) (Enveloped)

	ARCE Senior Project (Tilt Leg System)	SK-10
		Senior Project (Tilt Leg System).r3d

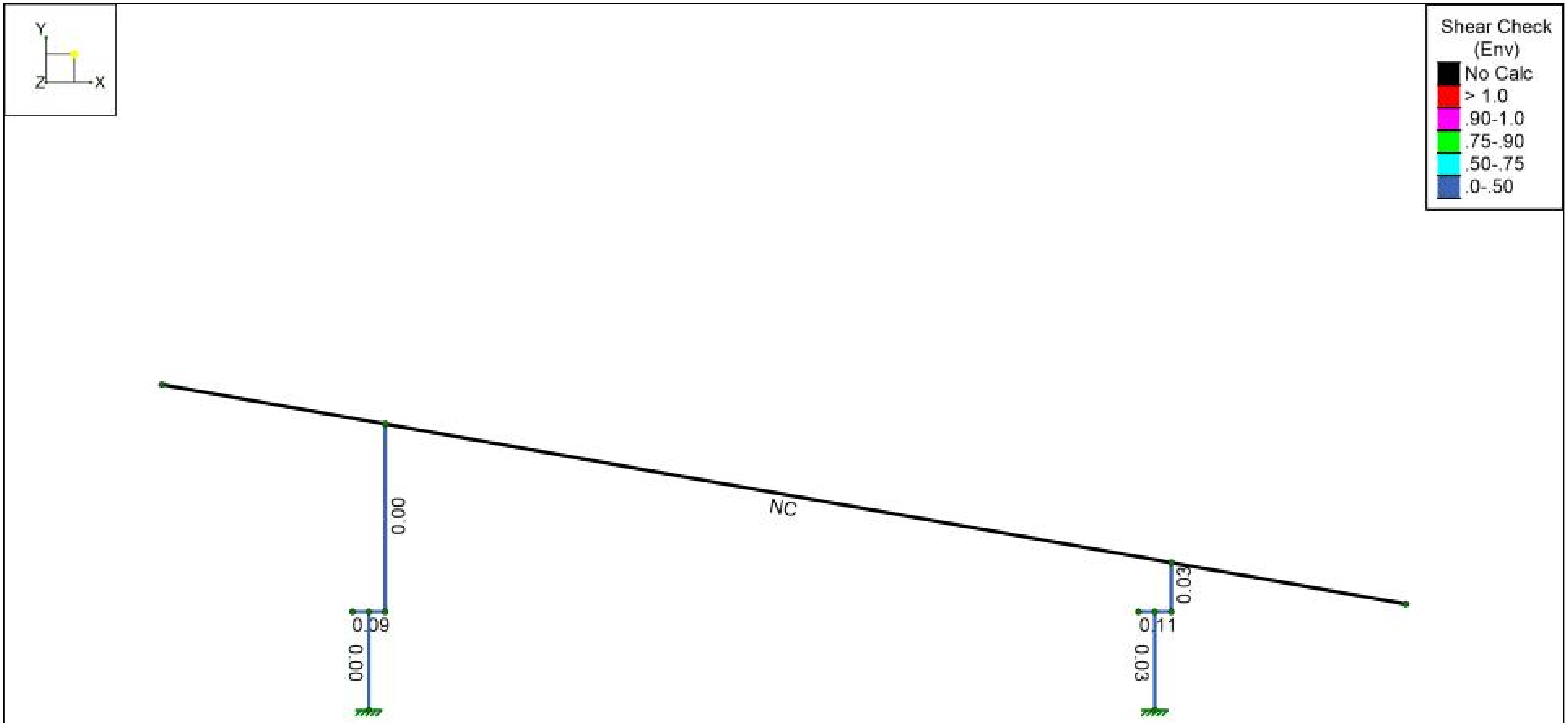


Envelope Only Solution
Member z Bending Moments (lb-ft) (Enveloped)

	ARCE Senior Project (Tilt Leg System)	SK-11
		Senior Project (Tilt Leg System).r3d



	ARCE Senior Project (Tilt Leg System)	SK-12
		Senior Project (Tilt Leg System).r3d



Member Shear Checks Displayed (Enveloped)
Envelope Only Solution

	ARCE Senior Project (Tilt Leg System)	SK-13
		Senior Project (Tilt Leg System).r3d

Aluminum Properties

	Label	E [ksi]	G [ksi]	Nu	Therm. Coeff. $[1e^{5}{}^{\circ}F^{-1}]$	Density $[k/ft^3]$	Table B.4	kt	Ftu [ksi]	Fty [ksi]	Fcy [ksi]	Fsu [ksi]	Ct
1	3003-H14	10100	3787.5	0.33	1.3	0.173	Table B.4-1	1	19	16	13	12	141
2	6061-T6	10100	3787.5	0.33	1.3	0.173	Table B.4-2	1	38	35	35	24	141
3	6005A-T61	10100	3787.5	0.33	1.3	0.173	Table B.4-2	1	38	35	35	24	141
4	6063-T5	10100	3787.5	0.33	1.3	0.173	Table B.4-2	1	22	16	16	13	141
5	6063-T6	10100	3787.5	0.33	1.3	0.173	Table B.4-2	1	30	25	25	19	141
6	5052-H34	10200	3787.5	0.33	1.3	0.173	Table B.4-1	1	34	26	24	20	141
7	6061-T6 W	10100	3787.5	0.33	1.3	0.173	Table B.4-1	1	24	15	15	15	141

Aluminum Design Parameters

	Label	Shape	Length [in]	Lcomp top [in]	Function
1	M1	1.96X0.26	2	Lbyy	Lateral
2	M2	1.61X0.26	2	Lbyy	Lateral
3	M3	1.96X0.26	11.464	Lbyy	Lateral
4	M4	1.61X0.26	3	Lbyy	Lateral
5	M6	STANDOFF	6		Lateral
6	M7	STANDOFF	6		Lateral

Basic Load Cases

	BLC Description	Category	Distributed
1	Dead	DL	1
2	Wind Uplift	WL	1
3	Wind Downward	WL	1
4	Snow	SL	1

Load Combinations

	Description	Solve	PDelta	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
1	Deflection 1	Yes	Y	DL	1										
2	Deflection 2	Yes	Y	LL	1										
3	Deflection 3	Yes	Y	DL	1	LL	1								
4	ASCE ASD 1	Yes	Y	DL	1										
5	ASCE ASD 2	Yes	Y	DL	1	LL	1	LLS	1						
6	ASCE ASD 3 (b)	Yes	Y	DL	1	SL	1	SLN	1						
7	ASCE ASD 4 (b)	Yes	Y	DL	1	LL	0.75	LLS	0.75	SL	0.75	SLN	0.75		
8	ASCE ASD 5 (a)	Yes	Y	DL	1	2	0.6								
9	ASCE ASD 5 (a)	Yes	Y	DL	1	3	0.6								
10	ASCE ASD 6 (a)	Yes	Y	DL	1	2	0.45	LL	0.75	LLS	0.75				
11	ASCE ASD 6 (a)	Yes	Y	DL	1	3	0.45	LL	0.75	LLS	0.75				
12	ASCE ASD 6 (c)	Yes	Y	DL	1	2	0.45	LL	0.75	LLS	0.75	SL	0.75	SLN	0.75
13	ASCE ASD 6 (c)	Yes	Y	DL	1	3	0.45	LL	0.75	LLS	0.75	SL	0.75	SLN	0.75
14	ASCE ASD 7	Yes	Y	DL	0.6	2	0.6								
15	ASCE ASD 7	Yes	Y	DL	0.6	3	0.6								

Envelope AA ADM1-10: ASD - Building Aluminum Code Checks

	Member	Shape	Code Check	Loc[in]	LC	Shear Check	Loc[in]	Dir	LC	Pnc/Om[lb]	Pnt/Om[lb]	Mny/Om[lb-ft]	Mnz/Om[lb-ft]	Vny/Om[lb]	Vnz/Om[lb]	Cb	Eqn
1	M1	1.96X0.26	0.708	1	9	0.091	2	z	9	8615.116	9930.667	50.75	382.543	6485.818	6485.818	1	H.1-1
2	M2	1.61X0.26	0.642	1	9	0.106	2	z	9	7076.606	8157.333	41.682	258.119	5327.636	5327.636	1	H.1-1
3	M3	1.96X0.26	0.788	0	9	0.004	11.464	z	9	1121.864	9930.667	50.75	327.135	6485.818	6485.818	1	H.1-1
4	M4	1.61X0.26	0.634	3	15	0.033	3	z	15	6370.498	8157.333	41.682	258.119	5327.636	5327.636	1	H.1-1
5	M6	STANDOFF	0.313	0	9	0.004	6		14	9205.707	11156.227	144.465	144.465	6693.736	6693.736	1.099	H.3-4
6	M7	STANDOFF	0.485	6	15	0.026	6		15	9205.707	11156.227	144.465	144.465	6693.736	6693.736	2.155	H.3-4

Envelope Member Section Forces

	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
1	M1	1	max	0	15	0	15	0	15	0	15	0	15	0	15
2			min	0	1	0	1	0	1	0	1	0	1	0	1
3		2	max	0	15	0	15	0	15	0	15	0	15	0	15

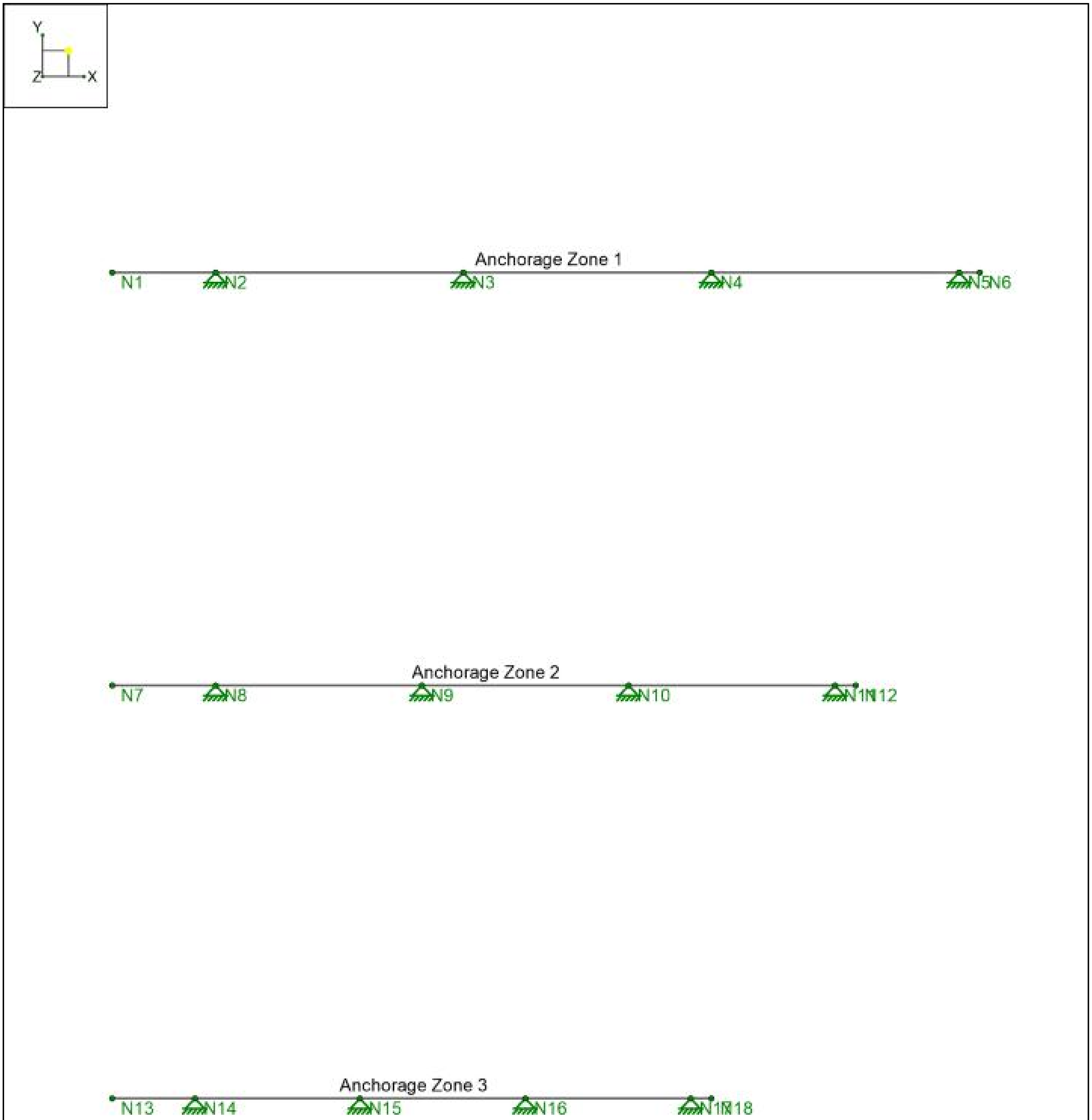
Envelope Member Section Forces (Continued)

	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
4			min	0	1	0	1	0	1	0	1	0	1	0	1
5		3	max	18.779	9	0	15	512.266	14	0	15	35.921	9	0	15
6			min	-24.433	14	0	1	-590.736	9	0	1	-31.291	14	0	1
7		4	max	18.779	9	0	15	512.266	14	0	15	11.307	9	0	15
8			min	-24.433	14	0	1	-590.736	9	0	1	-9.947	14	0	1
9		5	max	18.779	9	0	15	512.266	14	0	15	11.398	14	0	15
10			min	-24.433	14	0	1	-590.736	9	0	1	-13.307	9	0	1
11	M2	1	max	0	15	0	15	0	15	0	15	0	15	0	15
12			min	0	1	0	1	0	1	0	1	0	1	0	1
13		2	max	0	15	0	15	0	15	0	15	0	15	0	15
14			min	0	1	0	1	0	1	0	1	0	1	0	1
15		3	max	168.442	15	0	15	489.724	14	0	15	25.773	9	0	15
16			min	-162.901	8	0	1	-566.365	9	0	1	-22.09	14	0	1
17		4	max	168.442	15	0	15	489.724	14	0	15	2.174	9	0	15
18			min	-162.901	8	0	1	-566.365	9	0	1	-1.685	14	0	1
19		5	max	168.442	15	0	15	489.724	14	0	15	18.72	14	0	15
20			min	-162.901	8	0	1	-566.365	9	0	1	-21.424	9	0	1
21	M3	1	max	590.398	9	0	15	23.812	9	0	15	11.398	14	0	15
22			min	-512.627	14	0	1	-20.511	14	0	1	-13.307	9	0	1
23		2	max	590.398	9	0	15	23.812	9	0	15	6.499	14	0	15
24			min	-512.627	14	0	1	-20.511	14	0	1	-7.62	9	0	1
25		3	max	590.398	9	0	15	23.812	9	0	15	1.6	14	0	15
26			min	-512.627	14	0	1	-20.511	14	0	1	-1.933	9	0	1
27		4	max	590.398	9	0	15	23.812	9	0	15	3.754	9	0	15
28			min	-512.627	14	0	1	-20.511	14	0	1	-3.3	8	0	1
29		5	max	590.398	9	0	15	23.812	9	0	15	9.441	9	0	15
30			min	-512.627	14	0	1	-20.511	14	0	1	-8.197	14	0	1
31	M4	1	max	566.231	9	0	15	175.932	15	0	15	18.72	14	0	15
32			min	-489.662	14	0	1	-156.881	8	0	1	-21.424	9	0	1
33		2	max	566.231	9	0	15	175.932	15	0	15	8.94	14	0	15
34			min	-489.662	14	0	1	-156.881	8	0	1	-10.447	9	0	1
35		3	max	566.231	9	0	15	175.932	15	0	15	0.855	15	0	15
36			min	-489.662	14	0	1	-156.881	8	0	1	-1.166	8	0	1
37		4	max	566.231	9	0	15	175.932	15	0	15	11.851	15	0	15
38			min	-489.662	14	0	1	-156.881	8	0	1	-10.971	8	0	1
39		5	max	566.231	9	0	15	175.932	15	0	15	22.847	15	0	15
40			min	-489.662	14	0	1	-156.881	8	0	1	-20.776	8	0	1
41	M5	1	max	0	15	0	9	0	15	0	15	0	15	0	15
42			min	0	1	0	8	0	1	0	1	0	1	0	1
43		2	max	67.467	14	291.84	9	0	15	0	15	0	15	17.999	14
44			min	-79.84	9	-254.176	14	0	1	0	1	0	1	-20.557	9
45		3	max	70.449	8	0.704	14	0	15	0	15	0	15	221.754	14
46			min	-76.005	15	-1.129	11	0	1	0	1	0	1	-254.318	9
47		4	max	74.636	8	255.585	14	0	15	0	15	0	15	16.153	8
48			min	-73.493	15	-293.919	9	0	1	0	1	0	1	-17.622	15
49		5	max	0	15	0.002	9	0	15	0	15	0	15	0	15
50			min	0	1	-0.001	8	0	1	0	1	0	1	0	1
51	M6	1	max	590.398	9	16.158	9	0	15	0	15	0	15	35.921	9
52			min	-512.627	14	-26.112	14	0	1	0	1	0	1	-31.291	14
53		2	max	590.398	9	16.158	9	0	15	0	15	0	15	33.901	9
54			min	-512.627	14	-26.112	14	0	1	0	1	0	1	-28.027	14
55		3	max	590.398	9	16.158	9	0	15	0	15	0	15	31.881	9
56			min	-512.627	14	-26.112	14	0	1	0	1	0	1	-24.763	14
57		4	max	590.398	9	16.158	9	0	15	0	15	0	15	29.862	9
58			min	-512.627	14	-26.112	14	0	1	0	1	0	1	-21.499	14
59		5	max	590.398	9	16.158	9	0	15	0	15	0	15	27.842	9
60			min	-512.627	14	-26.112	14	0	1	0	1	0	1	-18.235	14
61	M7	1	max	566.231	9	171.112	15	0	15	0	15	0	15	25.773	9

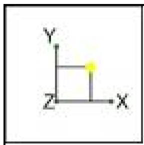
Envelope Member Section Forces (Continued)

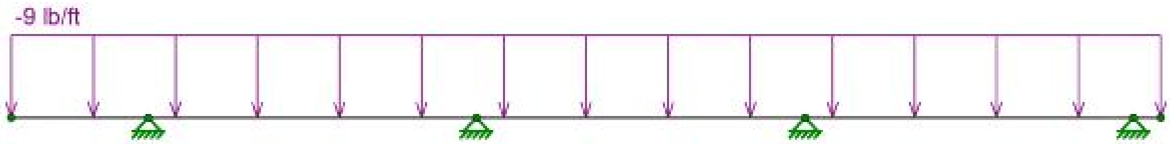
	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
62			min	-489.662	14	-160.598	8	0	1	0	1	0	1	-22.09	14
63		2	max	566.231	9	171.112	15	0	15	0	15	0	15	4.567	13
64			min	-489.662	14	-160.598	8	0	1	0	1	0	1	-2.064	14
65		3	max	566.231	9	171.112	15	0	15	0	15	0	15	19.416	8
66			min	-489.662	14	-160.598	8	0	1	0	1	0	1	-18.371	15
67		4	max	566.231	9	171.112	15	0	15	0	15	0	15	39.491	8
68			min	-489.662	14	-160.598	8	0	1	0	1	0	1	-39.76	15
69		5	max	566.231	9	171.112	15	0	15	0	15	0	15	59.566	8
70			min	-489.662	14	-160.598	8	0	1	0	1	0	1	-61.149	15

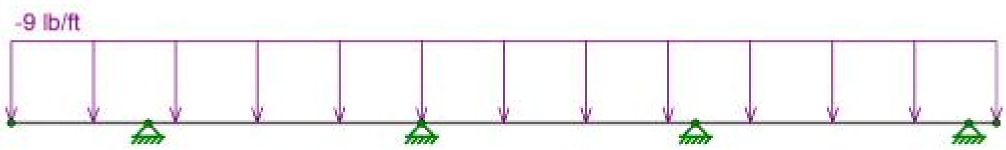
Solar Module Racking Anchorage RISA Graphics and Report

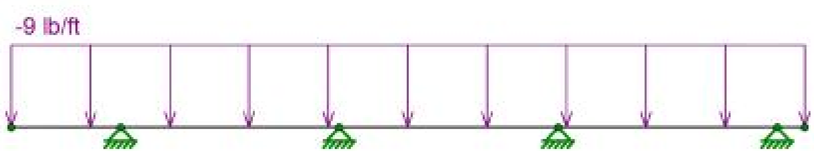


	ARCE Senior Project (Anchorage)	SK-1
ROK		
		Senior Project (Anchorage).r3d



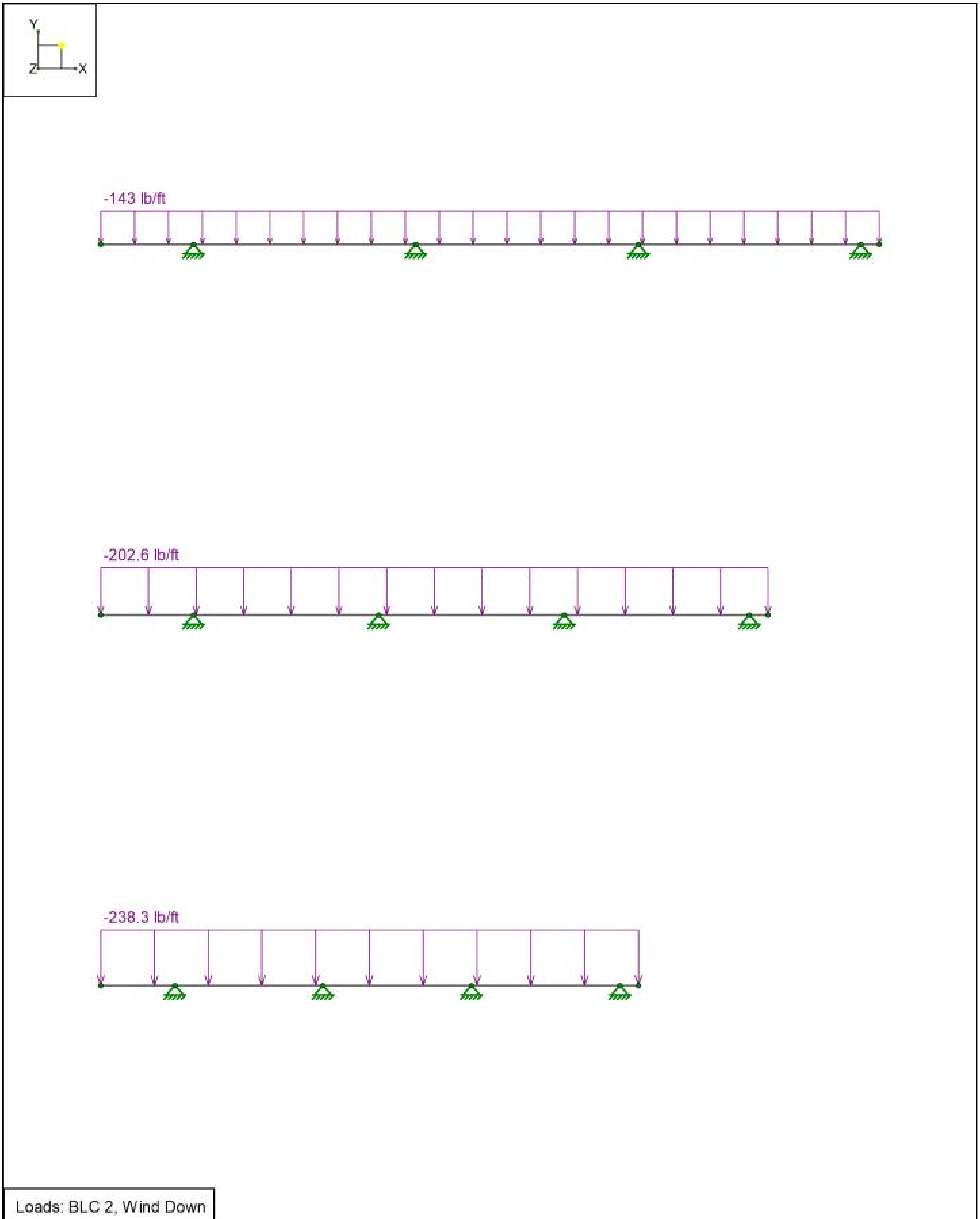






Loads: BLC 1, Dead

	ARCE Senior Project (Anchorage)	SK-2
ROK		
		Senior Project (Anchorage).r3d



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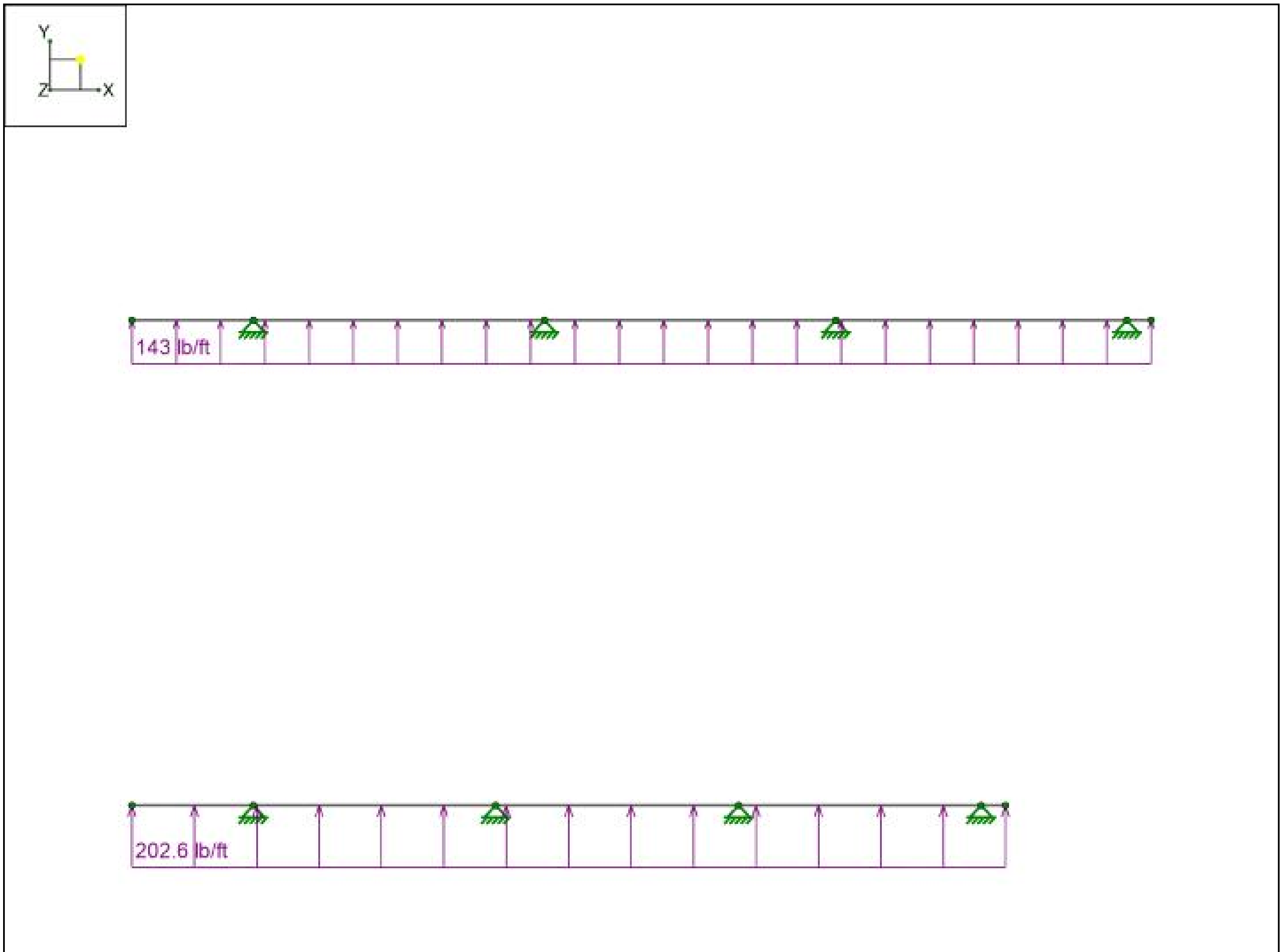
ROK		
		Senior Project (Anchorage).r3d



	ARCE Senior Project (Anchorage)	SK-4
ROK		
		Senior Project (Anchorage).r3d

Basic Load Cases

	BLC Description	Category	Distributed
1	Dead	DL	3
2	Wind Down	WL	3
3	Wind Uplift	WL	3

Load Combinations

	Description	Solve	PDelta	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
1	ASCE ASD 1	Yes	Y	DL	1						
2	ASCE ASD 2	Yes	Y	DL	1	LL	1	LLS	1		
3	ASCE ASD 5 (a)	Yes	Y	DL	1	2	0.6				
4	ASCE ASD 5 (a)	Yes	Y	DL	1	3	0.6				
5	ASCE ASD 6 (a)	Yes	Y	DL	1	2	0.45	LL	0.75	LLS	0.75
6	ASCE ASD 6 (a)	Yes	Y	DL	1	3	0.45	LL	0.75	LLS	0.75
7	ASCE ASD 7	Yes	Y	DL	0.6	2	0.6				
8	ASCE ASD 7	Yes	Y	DL	0.6	3	0.6				
9	Wind Down Only		Y	2	1						

Member Distributed Loads

	Member Label	Direction	Start Magnitude [lb/ft, F, ksf]	End Magnitude [lb/ft, F, ksf]	Start Location [(ft, %)]	End Location [(ft, %)]	Inactive [(lb, lb-ft), (in, rad), (lb*s²/ft, lb*s²*ft)]
1	Anchorage Zone 1	Y	-9	-9	0	%100	Active
2	Anchorage Zone 2	Y	-9	-9	0	%100	Active
3	Anchorage Zone 3	Y	-9	-9	0	%100	Active

Member Distributed Loads

	Member Label	Direction	Start Magnitude [lb/ft, F, ksf]	End Magnitude [lb/ft, F, ksf]	Start Location [(ft, %)]	End Location [(ft, %)]	Inactive [(lb, lb-ft), (in, rad), (lb*s²/ft, lb*s²*ft)]
1	Anchorage Zone 1	Y	-143	-143	0	%100	Active
2	Anchorage Zone 2	Y	-202.6	-202.6	0	%100	Active
3	Anchorage Zone 3	Y	-238.3	-238.3	0	%100	Active

Member Distributed Loads

	Member Label	Direction	Start Magnitude [lb/ft, F, ksf]	End Magnitude [lb/ft, F, ksf]	Start Location [(ft, %)]	End Location [(ft, %)]	Inactive [(lb, lb-ft), (in, rad), (lb*s²/ft, lb*s²*ft)]
1	Anchorage Zone 1	Y	143	143	0	%100	Active
2	Anchorage Zone 2	Y	202.6	202.6	0	%100	Active
3	Anchorage Zone 3	Y	238.3	238.3	0	%100	Active

Envelope Node Reactions

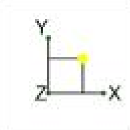
	Node Label		X [lb]	LC	Y [lb]	LC	Z [lb]	LC	MX [lb-ft]	LC	MY [lb-ft]	LC	MZ [lb-ft]	LC
1	N4	max	0	8	642.101	3	0	8	LOCKED		0	8	0	8
2		min	0	1	-544.567	8	0	1	LOCKED		0	1	0	1
3	N2	max	0	8	526.896	3	0	8	0	8	0	8	0	8
4		min	0	1	-446.861	8	0	1	0	1	0	1	0	1
5	N3	max	0	8	547.605	3	0	8	0	8	0	8	0	8
6		min	0	1	-464.425	8	0	1	0	1	0	1	0	1
7	N5	max	0	8	274.197	3	0	8	0	8	0	8	0	8
8		min	0	1	-232.547	8	0	1	0	1	0	1	0	1
9	N11	max	0	8	325.228	3	0	8	0	8	0	8	0	8
10		min	0	1	-289.357	8	0	1	0	1	0	1	0	1
11	N8	max	0	8	690.555	3	0	8	0	8	0	8	0	8
12		min	0	1	-614.391	8	0	1	0	1	0	1	0	1
13	N9	max	0	8	589.174	3	0	8	LOCKED		0	8	0	8
14		min	0	1	-524.191	8	0	1	LOCKED		0	1	0	1
15	N10	max	0	8	745.123	3	0	8	0	8	0	8	0	8
16		min	0	1	-662.94	8	0	1	0	1	0	1	0	1
17	N17	max	0	8	320.296	3	0	8	0	8	0	8	0	8
18		min	0	1	-289.949	8	0	1	0	1	0	1	0	1
19	N16	max	0	8	690.979	3	0	8	LOCKED		0	8	0	8
20		min	0	1	-625.509	8	0	1	LOCKED		0	1	0	1

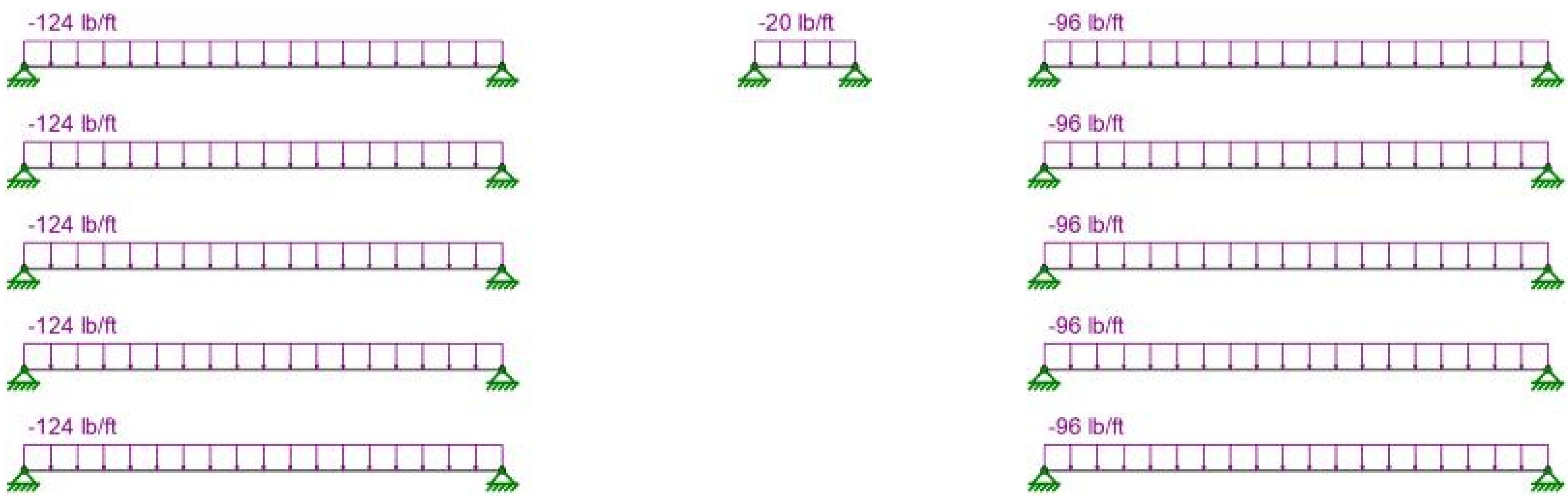
Envelope Node Reactions (Continued)

	Node Label		X [lb]	LC	Y [lb]	LC	Z [lb]	LC	MX [lb-ft]	LC	MY [lb-ft]	LC	MZ [lb-ft]	LC
21	N14	max	0	8	642.912	3	0	8	0	8	0	8	0	8
22		min	0	1	-581.997	8	0	1	0	1	0	1	0	1
23	N15	max	0	8	549.522	3	0	8	0	8	0	8	0	8
24		min	0	1	-497.455	8	0	1	0	1	0	1	0	1
25	Totals:	max	0	8	6544.59	3	0	8						
26		min	0	1	-5774.19	8	0	1						

Existing Building Framing RISA Graphics and Report:
Buildings 1, 2, & 5

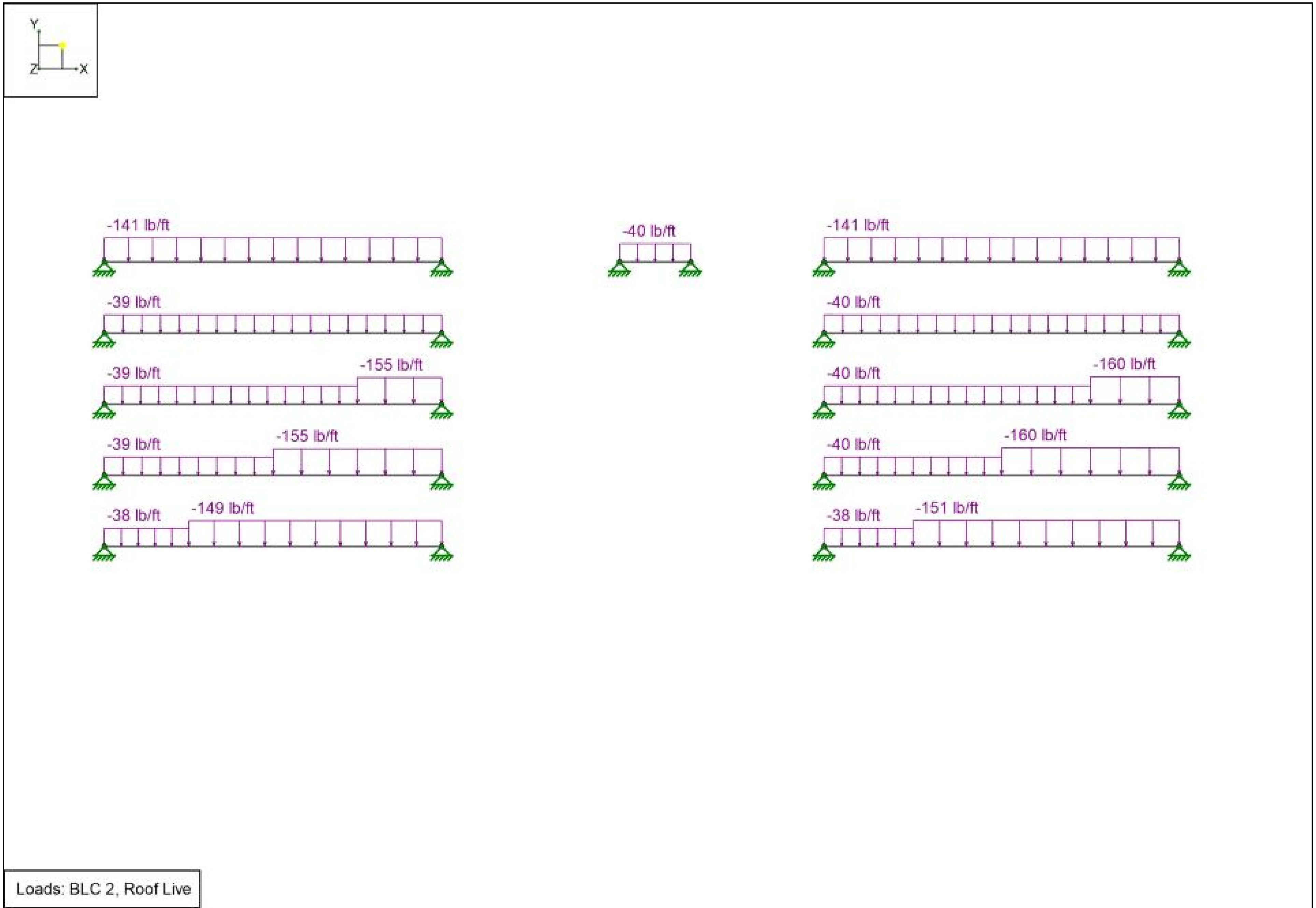
	ARCE Senior Project (Existing Framing)	SK-1
ROK		
		Senior Project (Existing Framing).r3d





Loads: BLC 1, Dead

	ARCE Senior Project (Existing Framing)	SK-2
ROK		
		Senior Project (Existing Framing).r3d



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ROK		
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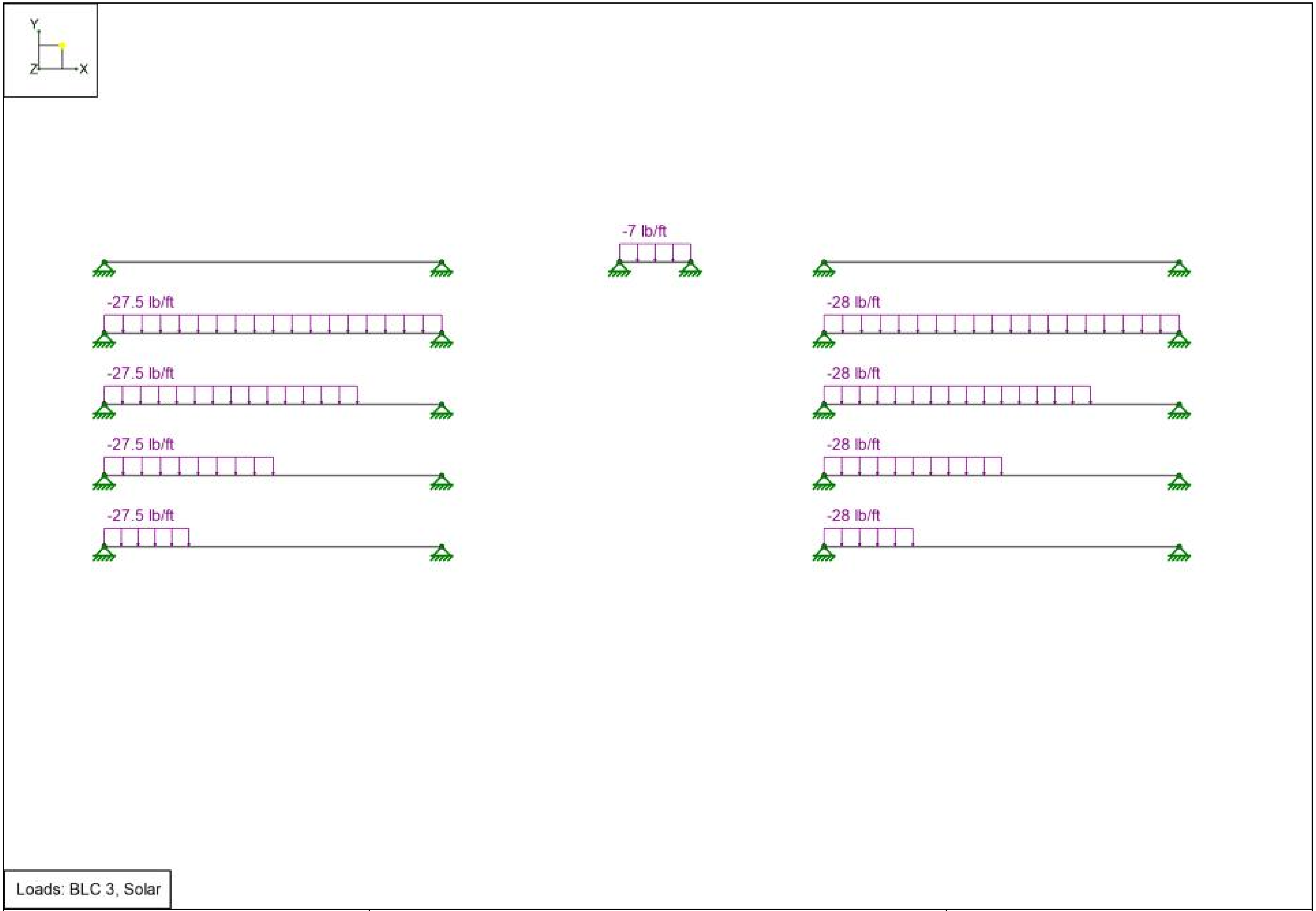
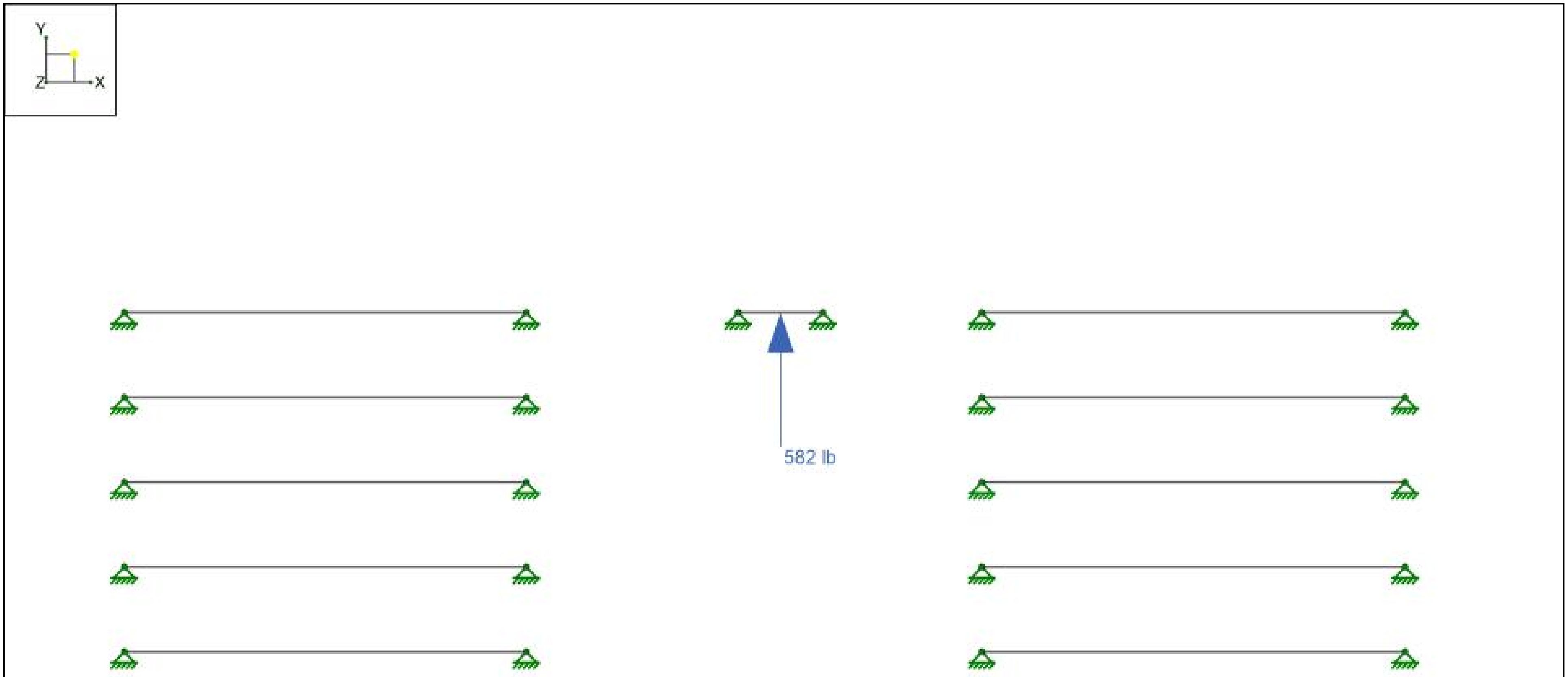
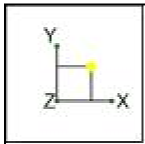


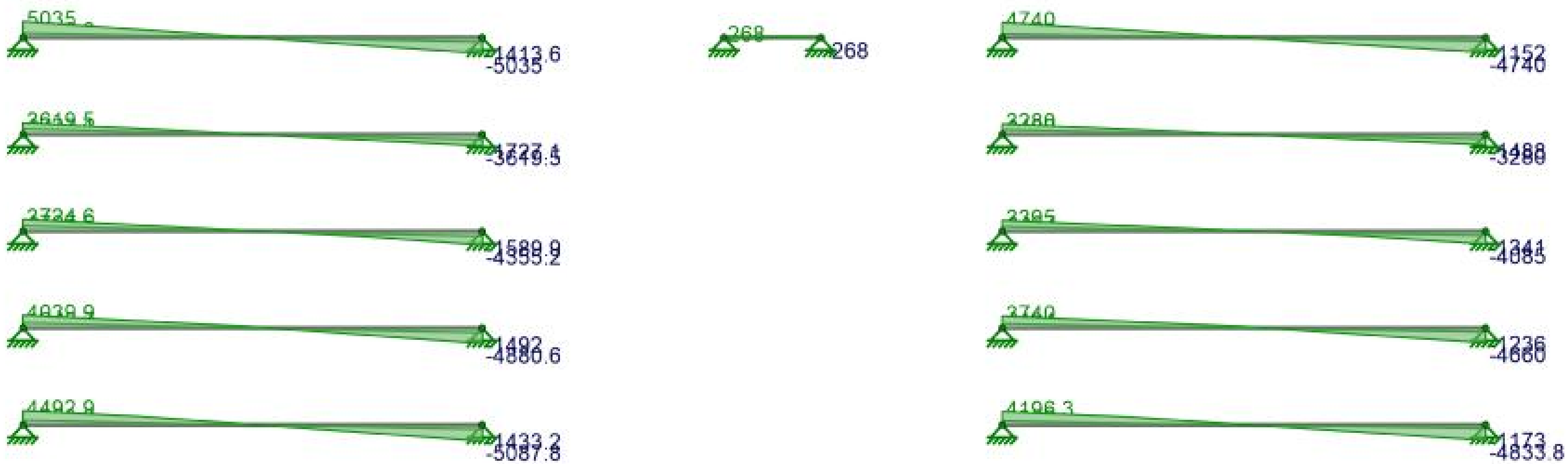
	ARCE Senior Project (Existing Framing)	SK-4
ROK		
		Senior Project (Existing Framing).r3d



Loads: BLC 4, Wind Uplift

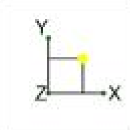
	ARCE Senior Project (Existing Framing)	SK-5
ROK		
		Senior Project (Existing Framing).r3d

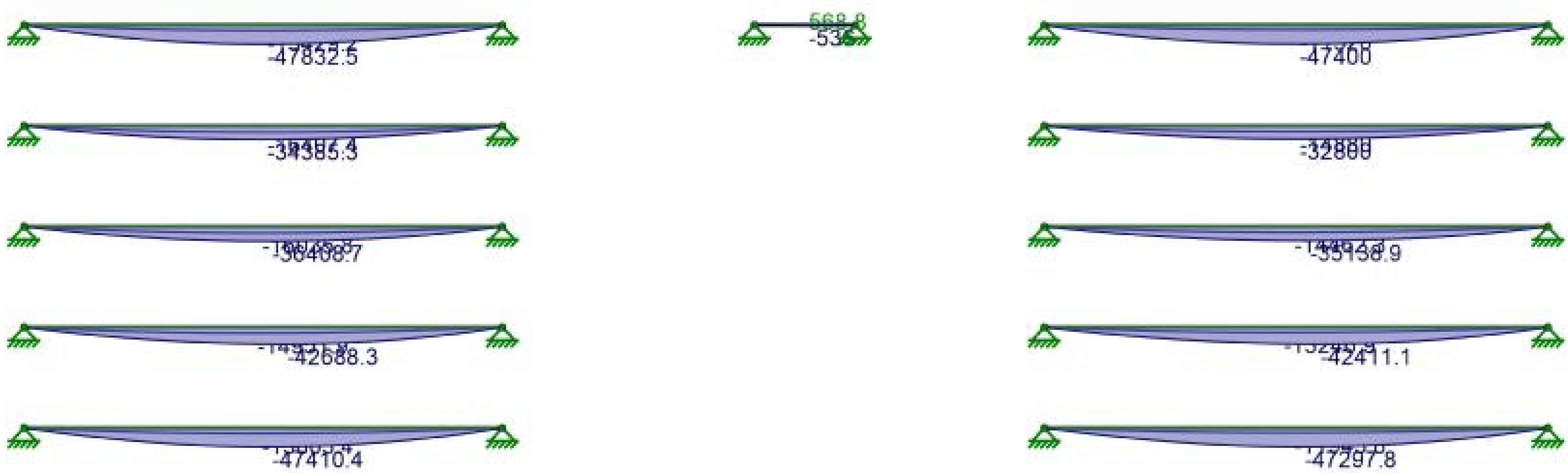




Envelope Only Solution
Member y Shear Forces (lbs) (Enveloped)

	ARCE Senior Project (Existing Framing)	SK-6
ROK		
		Senior Project (Existing Framing).r3d





Envelope Only Solution
Member z Bending Moments (lb-ft) (Enveloped)

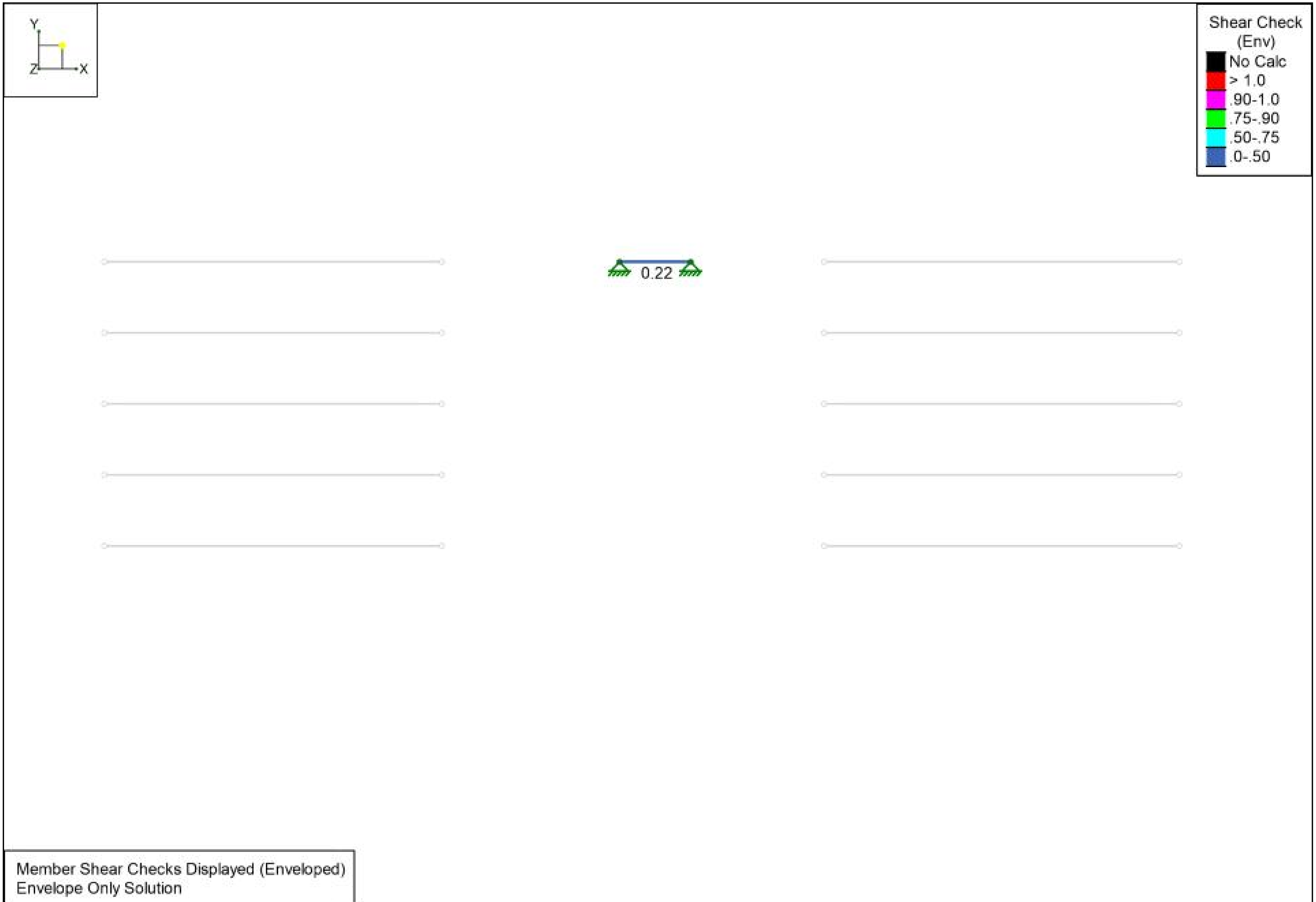
	ARCE Senior Project (Existing Framing)	SK-7
ROK		
		Senior Project (Existing Framing).r3d

Code Check (Env)

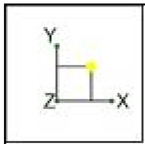
- No Calc
- > 1.0
- .90-1.0
- .75-.90
- .50-.75
- .0-.50

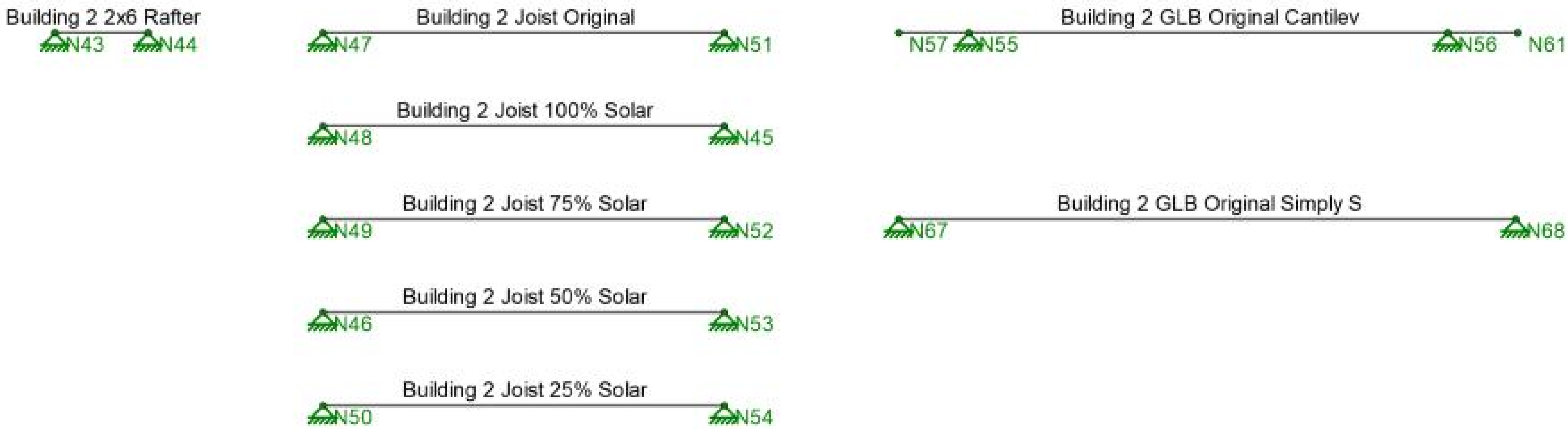
Member Code Checks Displayed (Enveloped)
Envelope Only Solution

	ARCE Senior Project (Existing Framing)	SK-8
ROK		
		Senior Project (Existing Framing).r3d

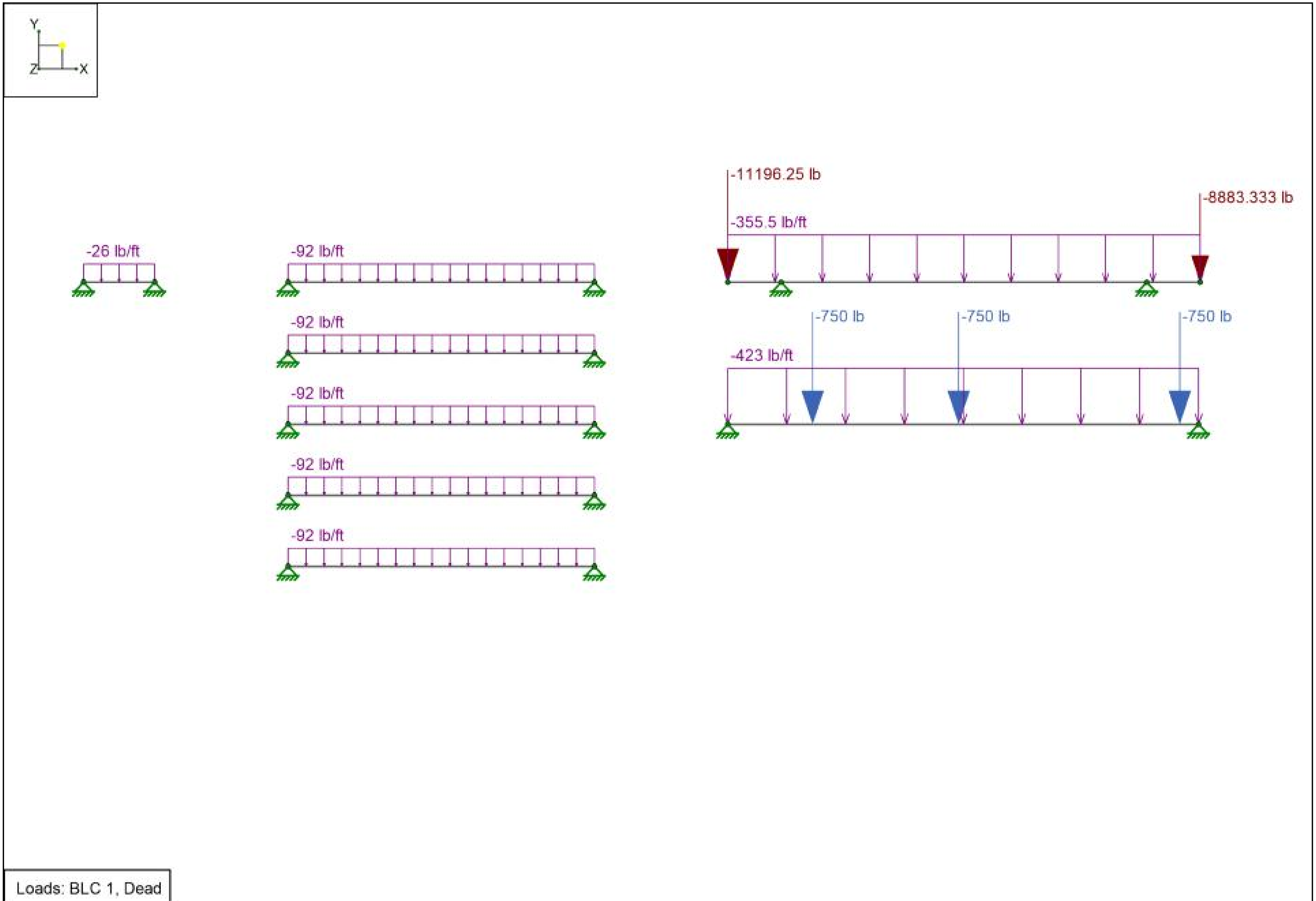


	ARCE Senior Project (Existing Framing)	SK-9
ROK		
		Senior Project (Existing Framing).r3d

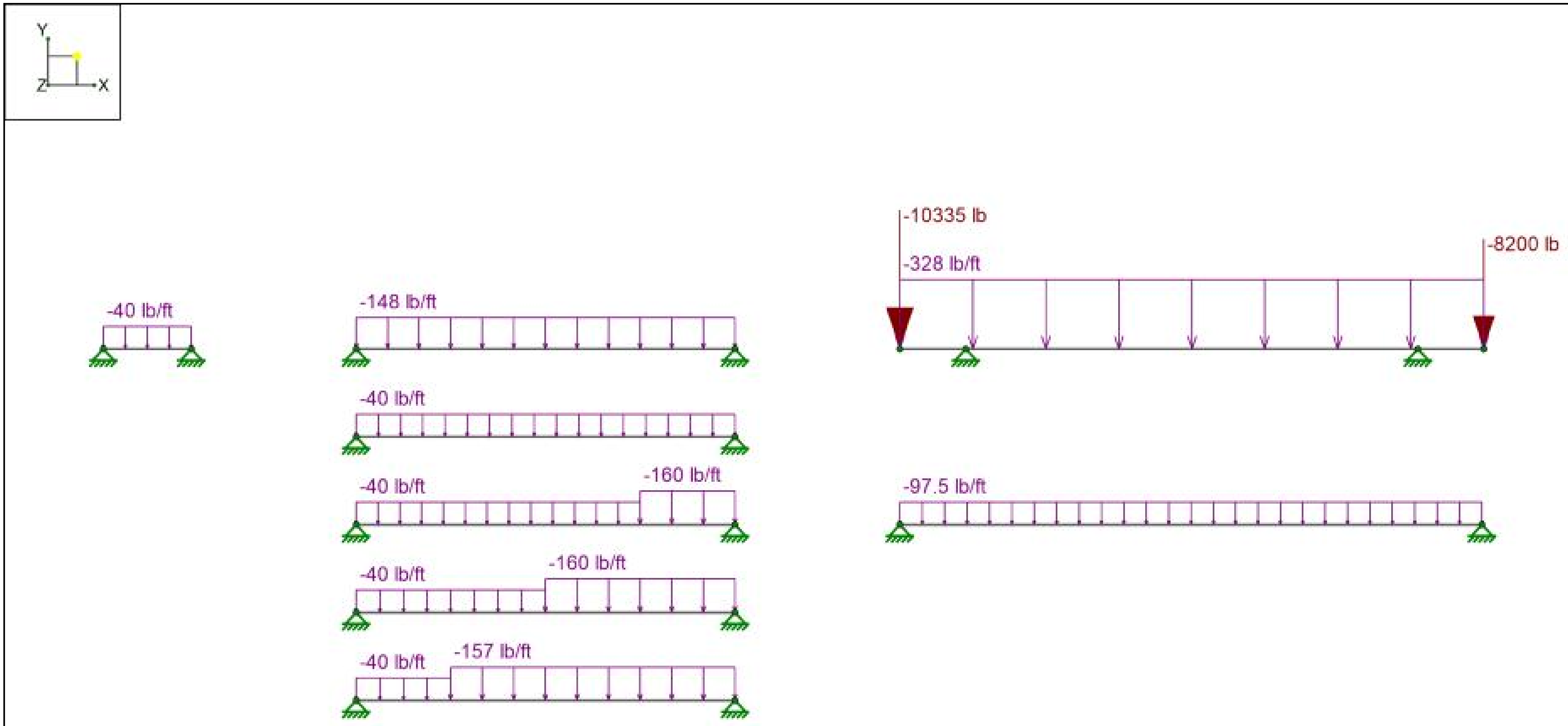




	ARCE Senior Project (Existing Framing)	SK-10
ROK		
		Senior Project (Existing Framing).r3d

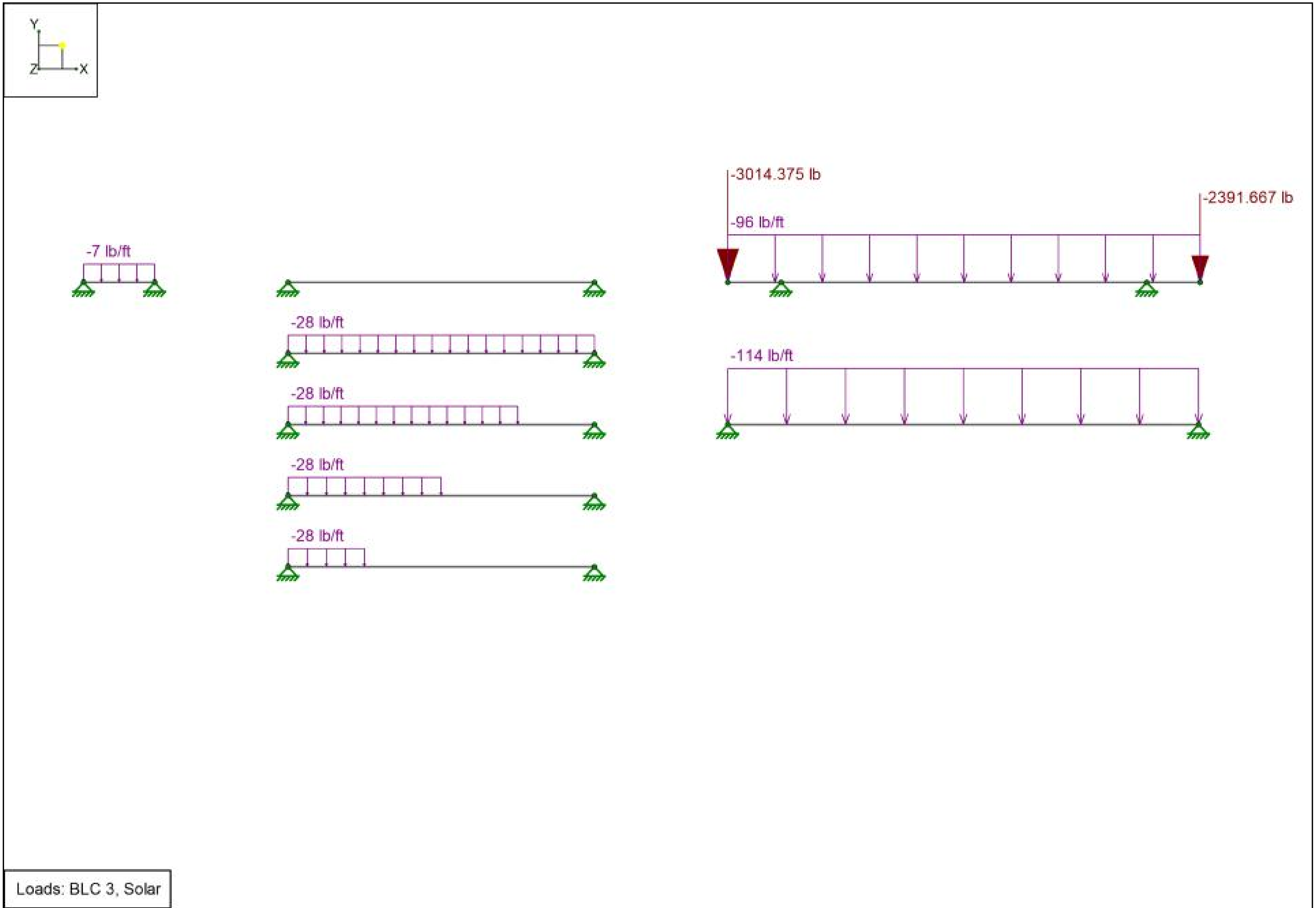


	ARCE Senior Project (Existing Framing)	SK-11
ROK		
		Senior Project (Existing Framing).r3d

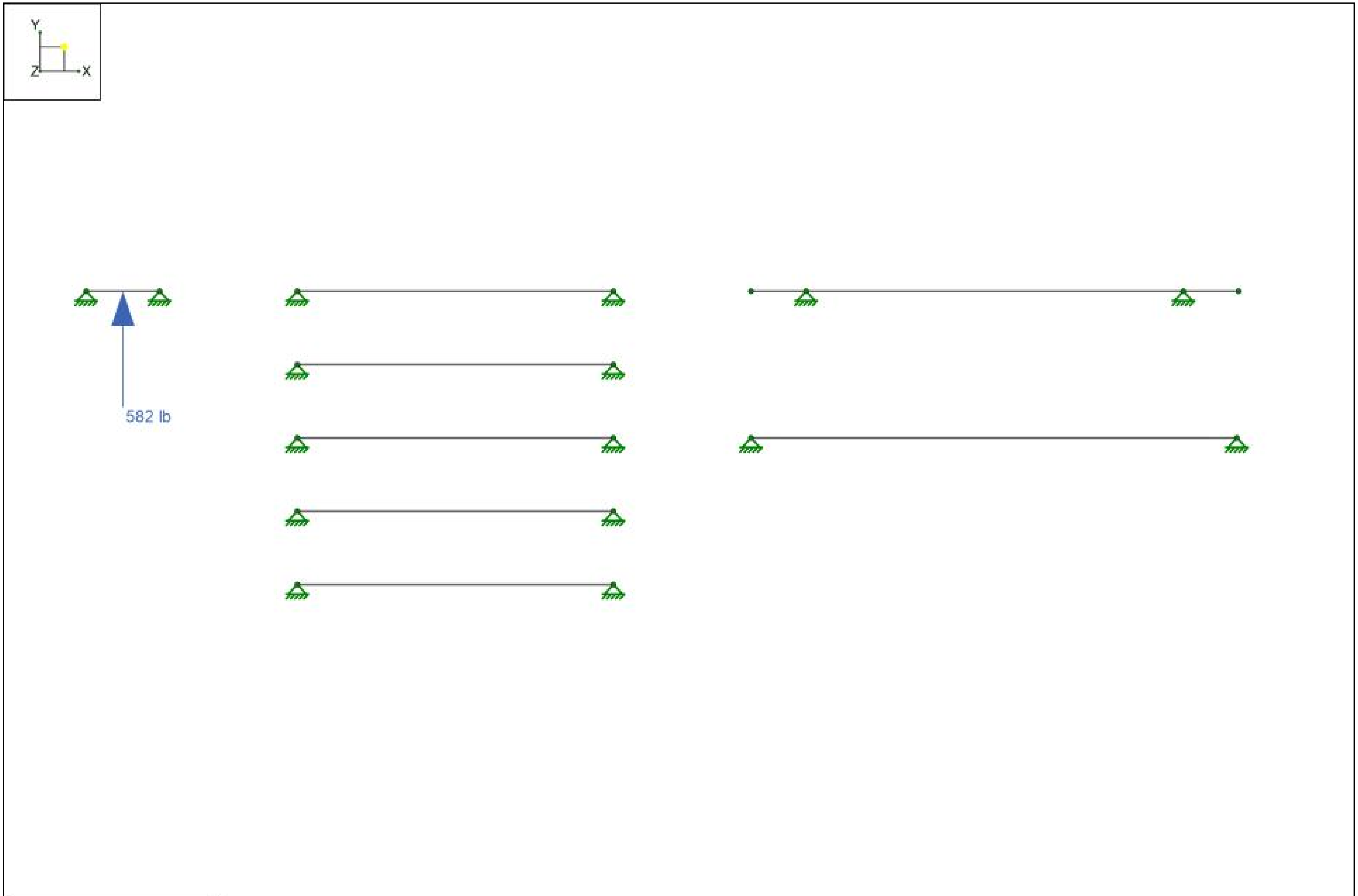


Loads: BLC 2, Roof Live

	ARCE Senior Project (Existing Framing)	SK-12
ROK		
		Senior Project (Existing Framing).r3d

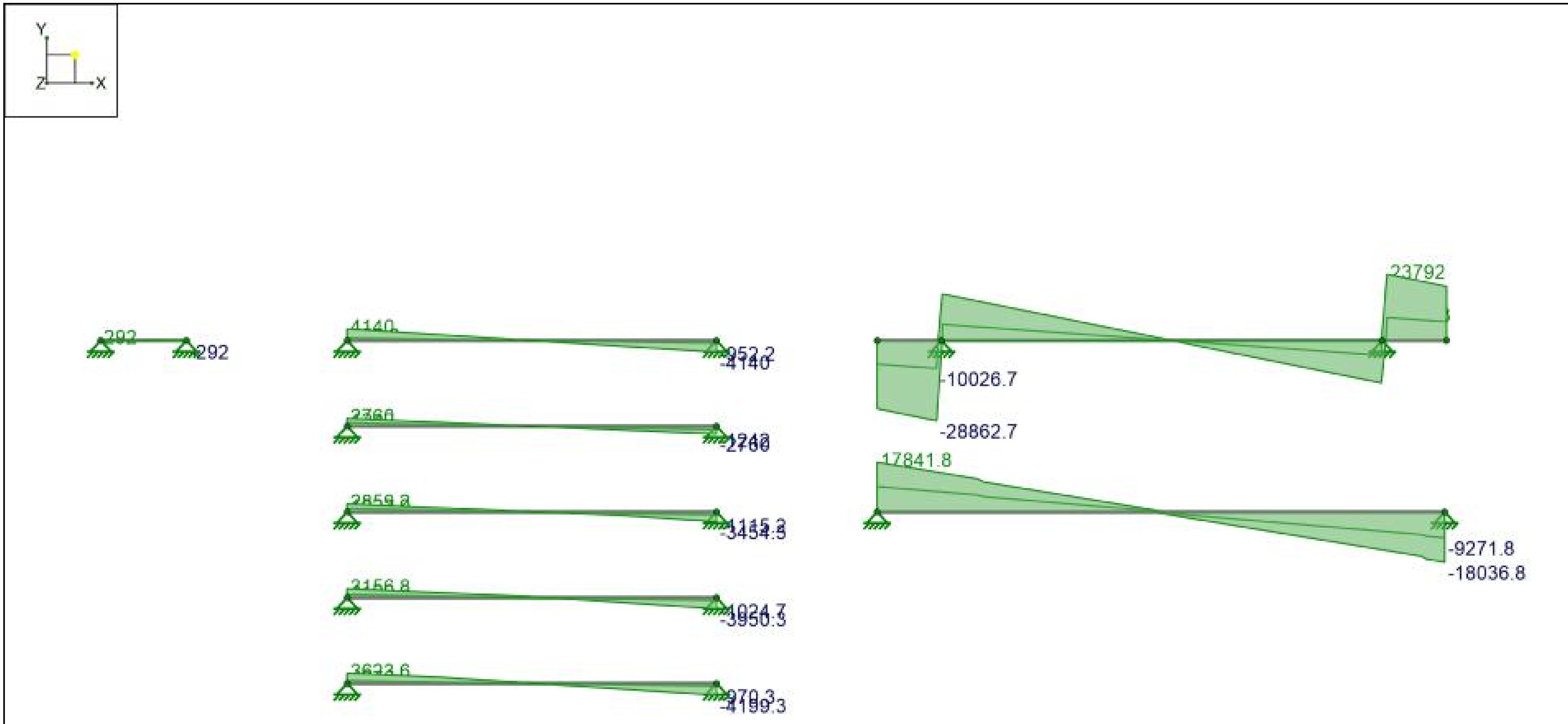


	ARCE Senior Project (Existing Framing)	SK-13
ROK		
		Senior Project (Existing Framing).r3d



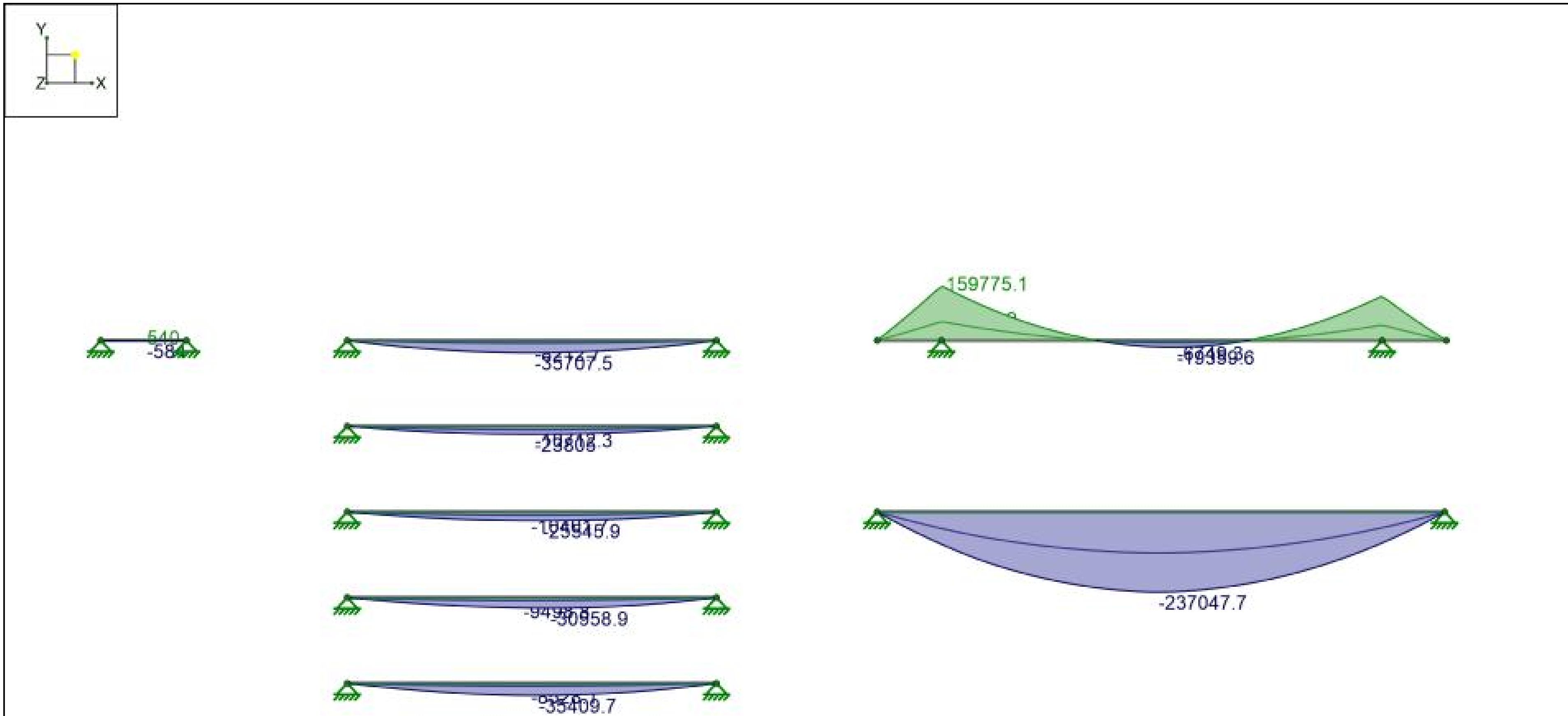
Loads: BLC 4, Wind Uplift

	ARCE Senior Project (Existing Framing)	SK-14
ROK		
		Senior Project (Existing Framing).r3d



Envelope Only Solution
Member y Shear Forces (lbs) (Enveloped)

	ARCE Senior Project (Existing Framing)	SK-15
ROK		
		Senior Project (Existing Framing).r3d



Envelope Only Solution
Member z Bending Moments (lb-ft) (Enveloped)

	ARCE Senior Project (Existing Framing)	SK-16
ROK		
		Senior Project (Existing Framing).r3d

	ARCE Senior Project (Existing Framing)	SK-17
ROK		
		Senior Project (Existing Framing).r3d

Member Shear Checks Displayed (Enveloped)
Envelope Only Solution

	ARCE Senior Project (Existing Framing)	SK-18
ROK		
		Senior Project (Existing Framing).r3d

Wood Material Properties

	Label	Type	Database	Species	Grade	Cm	Emod	Nu	Therm. Coeff. [$1e^5 °F^{-1}$]	Density [k/ft^3]
1	DF	Solid Sawn	Visually Graded	Douglas Fir-Larch	No.1		1	0.3	0.3	0.035
2	SP	Solid Sawn	Visually Graded	Douglas Fir-Larch	Select Structural		1	0.3	0.3	0.035
3	HF	Solid Sawn	Visually Graded	Hem-Fir	No.1		1	0.3	0.3	0.035
4	SPF	Solid Sawn	Visually Graded	Spruce-Pine-fir	No.1		1	0.3	0.3	0.035
5	24F-1.8E DF Balanced	Glulam	CSA Table 6.3	24f_E_DFL	na		1	0.3	0.3	0.035
6	24F-1.8E DF Unbalanced	Glulam	CSA Table 6.3	24f_E_DFL	na		1	0.3	0.3	0.035
7	24F-1.8E SP Balanced	Glulam	CSA Table 6.3	24f_E_DFL	na		1	0.3	0.3	0.035
8	24F-1.8E SP Unbalanced	Glulam	CSA Table 6.3	24f_E_DFL	na		1	0.3	0.3	0.035
9	1.3E-1600F_VERSALAM	SCL	Boise Cascade	1.3E-1600F_VERSALAM	na		1	0.3	0.3	0.035
10	1.35E LSL_SolidStart	SCL	Louisiana Pacific	1.35E LSL_SolidStart	na		1	0.3	0.3	0.035
11	1.3E_RIGIDLAM LVL	SCL	Roseburg Forest Products	1.3E_RIGIDLAM LVL	na		1	0.3	0.3	0.035
12	2.0E_DF Parallam PSL	SCL	TrusJoist	2.0E_DF Parallam PSL	na		1	0.3	0.3	0.035
13	LVL_PRL_1.5E_2250F	Custom	N/A	LVL_PRL_1.5E_2250F	na		1	0.3	0.3	0.035
14	LVL_Microlam_1.9E_2600F	Custom	N/A	LVL_Microllam_1.9E_2600F	na		1	0.3	0.3	0.035
15	PSL_Parallam_2.0E_2900F	Custom	N/A	PSL_Parallam_2.0E_2900F	na		1	0.3	0.3	0.035
16	LSL_TimberStrand_1.55E_2325F	Custom	N/A	LSL_TimberStrand_1.55E_2325F	na		1	0.3	0.3	0.035

Wood Design Parameters

	Label	Shape	Length [ft]	le-bend top [ft]	Cr	y sway	z sway
1	Building 5 2x6 Rafter	2X6	8	Lbyy			
2	Building 2 2x6 Rafter	2X6	8	Lbyy			
3	Building 2 GLB Original Cantilev	6.75X36FS	53.167	Lbyy			
4	Building 2 GLB Original Simply S	6.75X36FS	53	Lbyy			

Basic Load Cases

	BLC Description	Category	Nodal	Point	Distributed
1	Dead	DL	2	3	19
2	Roof Live	RLL	2		28
3	Solar	DL	2		16
4	Wind Uplift	WL		2	
5	Wind Down	WL			

Load Combinations

	Description	Solve	PDelta	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
1	ASCE ASD 1	Yes	Y	DL	1										
2	ASCE ASD 2	Yes	Y	DL	1	LL	1	LLS	1						
3	ASCE ASD 3 (a)	Yes	Y	DL	1	RLL	1								
4	ASCE ASD 4 (a)	Yes	Y	DL	1	LL	0.75	LLS	0.75	RLL	0.75				
5	ASCE ASD 5 (a)	Yes	Y	DL	1	4	0.6								
6	ASCE ASD 5 (a)	Yes	Y	DL	1	5	0.6								
7	ASCE ASD 6 (a)	Yes	Y	DL	1	4	0.45	LL	0.75	LLS	0.75	RLL	0.75		
8	ASCE ASD 6 (a)	Yes	Y	DL	1	5	0.45	LL	0.75	LLS	0.75	RLL	0.75		
9	ASCE ASD 6 (b)	Yes	Y	DL	1	4	0.45	LL	0.75	LLS	0.75	SL	0.75	SLN	0.75
10	ASCE ASD 6 (b)	Yes	Y	DL	1	5	0.45	LL	0.75	LLS	0.75	SL	0.75	SLN	0.75
11	ASCE ASD 6 (c)	Yes	Y	DL	1	4	0.45	LL	0.75	LLS	0.75	RL	0.75		
12	ASCE ASD 6 (c)	Yes	Y	DL	1	5	0.45	LL	0.75	LLS	0.75	RL	0.75		
13	ASCE ASD 7	Yes	Y	DL	0.6	4	0.6								
14	ASCE ASD 7	Yes	Y	DL	0.6	5	0.6								

Envelope Wood Code Checks

	Member	Shape	Code Check	Loc[ft]	LC	Shear Check	Loc[ft]	Dir	LC	Fc' [ksi]	Ft' [ksi]	Fb1' [ksi]	Fb2' [ksi]	Fv' [ksi]	RB	CL	CP	Eqn
1	Building 5 2x6 Rafter	2X6	0.548	4	3	0.217	8	y	3	0.123	1.097	1.551	1.869	0.225	15.319	0.954	0.06	3.9-3
2	Building 2 2x6 Rafter	2X6	0.597	4	3	0.236	8	y	3	0.123	1.097	1.551	1.869	0.225	15.319	0.954	0.06	3.9-3
3	Building 2 GLB Original Cantilev	6.75X36FS	0.595	6.092	3	0.491	5.538	y	3	0.09	2.774	2.211	1.94	0.363	22.452	0.53	0.016	3.9-3
4	Building 2 GLB Original Simply S	6.75X36FS	0.861	25.948	3	0.365	53	y	1	0.091	2.774	2.265	1.94	0.261	22.417	0.408	0.017	3.9-3

Envelope Member Section Forces

	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
1	Building 1 Joist Original	1	max	0	14	5035	3	0	14	0	14	0	14	0	14
2			min	0	1	1413.6	13	0	1	0	1	0	1	0	1
3		2	max	0	14	2517.5	3	0	14	0	14	0	14	-10071.9	14
4			min	0	1	706.8	13	0	1	0	1	0	1	-35874.375	3
5		3	max	0	14	0	14	0	14	0	14	0	14	-13429.2	14
6			min	0	1	0	1	0	1	0	1	0	1	-47832.5	3
7		4	max	0	14	-706.8	14	0	14	0	14	0	14	-10071.9	14
8			min	0	1	-2517.5	3	0	1	0	1	0	1	-35874.375	3
9		5	max	0	14	-1413.6	14	0	14	0	14	0	14	0	14
10			min	0	1	-5035	3	0	1	0	1	0	1	0	1
11	Building 1 Joist Full Solar	1	max	0	14	3619.5	3	0	14	0	14	0	14	0	14
12			min	0	1	1727.1	13	0	1	0	1	0	1	0	1
13		2	max	0	14	1809.75	3	0	14	0	14	0	14	-12305.587	14
14			min	0	1	863.55	13	0	1	0	1	0	1	-25788.937	3
15		3	max	0	14	0	14	0	14	0	14	0	14	-16407.45	14
16			min	0	1	0	1	0	1	0	1	0	1	-34385.25	3
17		4	max	0	14	-863.55	14	0	14	0	14	0	14	-12305.588	14
18			min	0	1	-1809.75	3	0	1	0	1	0	1	-25788.937	3
19		5	max	0	14	-1727.1	14	0	14	0	14	0	14	0	14
20			min	0	1	-3619.5	3	0	1	0	1	0	1	0	1
21	Building 1 Joist 75% Solar	1	max	0	14	3724.594	3	0	14	0	14	0	14	0	14
22			min	0	1	1707.506	13	0	1	0	1	0	1	0	1
23		2	max	0	14	1914.844	3	0	14	0	14	0	14	-12119.447	14
24			min	0	1	843.956	13	0	1	0	1	0	1	-26787.328	3
25		3	max	0	14	105.094	3	0	14	0	14	0	14	-16035.169	14
26			min	0	1	-32.656	1	0	1	0	1	0	1	-36382.031	3
27		4	max	0	14	-883.144	14	0	14	0	14	0	14	-11747.166	14
28			min	0	1	-1704.656	3	0	1	0	1	0	1	-28784.109	3
29		5	max	0	14	-1589.944	14	0	14	0	14	0	14	0	14
30			min	0	1	-4355.156	3	0	1	0	1	0	1	0	1
31	Building 1 Joist 50% Solar	1	max	0	14	4039.875	3	0	14	0	14	0	14	0	14
32			min	0	1	1648.725	13	0	1	0	1	0	1	0	1
33		2	max	0	14	2230.125	3	0	14	0	14	0	14	-11561.025	14
34			min	0	1	785.175	13	0	1	0	1	0	1	-29782.5	3
35		3	max	0	14	420.375	3	0	14	0	14	0	14	-14918.325	14
36			min	0	1	-130.625	1	0	1	0	1	0	1	-42372.375	3
37		4	max	0	14	-785.175	14	0	14	0	14	0	14	-10816.462	14
38			min	0	1	-2230.125	3	0	1	0	1	0	1	-33776.062	3
39		5	max	0	14	-1491.975	14	0	14	0	14	0	14	0	14
40			min	0	1	-4880.625	3	0	1	0	1	0	1	0	1
41	Building 1 Joist 25% Solar	1	max	0	14	4492.906	3	0	14	0	14	0	14	0	14
42			min	0	1	1550.756	13	0	1	0	1	0	1	0	1
43		2	max	0	14	2692.656	3	0	14	0	14	0	14	-10630.322	14
44			min	0	1	687.206	13	0	1	0	1	0	1	-34131.422	3
45		3	max	0	14	99.156	3	0	14	0	14	0	14	-13801.481	14
46			min	0	1	-32.656	1	0	1	0	1	0	1	-47392.531	3
47		4	max	0	14	-726.394	14	0	14	0	14	0	14	-10258.041	14
48			min	0	1	-2494.344	3	0	1	0	1	0	1	-36015.391	3
49		5	max	0	14	-1433.194	14	0	14	0	14	0	14	0	14
50			min	0	1	-5087.844	3	0	1	0	1	0	1	0	1
51	Building 5 2x6 Rafter	1	max	0	14	268	3	0	14	0	14	0	14	0	14
52			min	0	1	-109.8	13	0	1	0	1	0	1	0	1
53		2	max	0	14	134	3	0	14	0	14	0	14	252	13
54			min	0	1	-142.2	13	0	1	0	1	0	1	-402	3
55		3	max	0	14	174.6	13	0	14	0	14	0	14	568.8	13
56			min	0	1	0	1	0	1	0	1	0	1	-536	3
57		4	max	0	14	142.2	13	0	14	0	14	0	14	252	13
58			min	0	1	-134	3	0	1	0	1	0	1	-402	3

Envelope Member Section Forces (Continued)

	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
59		5	max	0	14	109.8	13	0	14	0	14	0	14	0	14
60			min	0	1	-268	3	0	1	0	1	0	1	0	1
61	Building 5 Joist Original	1	max	0	14	4740	3	0	14	0	14	0	14	0	14
62			min	0	1	1152	13	0	1	0	1	0	1	0	1
63		2	max	0	14	2370	3	0	14	0	14	0	14	-8640	14
64			min	0	1	576	13	0	1	0	1	0	1	-35550	3
65		3	max	0	14	0	14	0	14	0	14	0	14	-11520	14
66			min	0	1	0	1	0	1	0	1	0	1	-47400	3
67		4	max	0	14	-576	14	0	14	0	14	0	14	-8640	14
68			min	0	1	-2370	3	0	1	0	1	0	1	-35550	3
69		5	max	0	14	-1152	14	0	14	0	14	0	14	0	14
70			min	0	1	-4740	3	0	1	0	1	0	1	0	1
71	Building 5 Joist 100% Solar	1	max	0	14	3280	3	0	14	0	14	0	14	0	14
72			min	0	1	1488	13	0	1	0	1	0	1	0	1
73		2	max	0	14	1640	3	0	14	0	14	0	14	-11160	14
74			min	0	1	744	13	0	1	0	1	0	1	-24600	3
75		3	max	0	14	0	14	0	14	0	14	0	14	-14880	14
76			min	0	1	0	1	0	1	0	1	0	1	-32800	3
77		4	max	0	14	-744	14	0	14	0	14	0	14	-11160	14
78			min	0	1	-1640	3	0	1	0	1	0	1	-24600	3
79		5	max	0	14	-1488	14	0	14	0	14	0	14	0	14
80			min	0	1	-3280	3	0	1	0	1	0	1	0	1
81	Building 5 Joist 75% Solar	1	max	0	14	3395	3	0	14	0	14	0	14	0	14
82			min	0	1	1467	13	0	1	0	1	0	1	0	1
83		2	max	0	14	1755	3	0	14	0	14	0	14	-10950	14
84			min	0	1	723	13	0	1	0	1	0	1	-25750	3
85		3	max	0	14	115	3	0	14	0	14	0	14	-14460	14
86			min	0	1	-35	1	0	1	0	1	0	1	-35100	3
87		4	max	0	14	-765	14	0	14	0	14	0	14	-10530	14
88			min	0	1	-1525	3	0	1	0	1	0	1	-28050	3
89		5	max	0	14	-1341	14	0	14	0	14	0	14	0	14
90			min	0	1	-4085	3	0	1	0	1	0	1	0	1
91	Building 5 Joist 50% Solar	1	max	0	14	3740	3	0	14	0	14	0	14	0	14
92			min	0	1	1404	13	0	1	0	1	0	1	0	1
93		2	max	0	14	2100	3	0	14	0	14	0	14	-10320	14
94			min	0	1	660	13	0	1	0	1	0	1	-29200	3
95		3	max	0	14	460	3	0	14	0	14	0	14	-13200	14
96			min	0	1	-140	1	0	1	0	1	0	1	-42000	3
97		4	max	0	14	-660	14	0	14	0	14	0	14	-9480	14
98			min	0	1	-2100	3	0	1	0	1	0	1	-33800	3
99		5	max	0	14	-1236	14	0	14	0	14	0	14	0	14
100			min	0	1	-4660	3	0	1	0	1	0	1	0	1
101	Building 5 Joist 25% Solar	1	max	0	14	4196.25	3	0	14	0	14	0	14	0	14
102			min	0	1	1299	13	0	1	0	1	0	1	0	1
103		2	max	0	14	2576.25	3	0	14	0	14	0	14	-9270	14
104			min	0	1	555	13	0	1	0	1	0	1	-33862.5	3
105		3	max	0	14	106.25	3	0	14	0	14	0	14	-11940	14
106			min	0	1	-35	1	0	1	0	1	0	1	-47275	3
107		4	max	0	14	-597	14	0	14	0	14	0	14	-8850	14
108			min	0	1	-2363.75	3	0	1	0	1	0	1	-35987.5	3
109		5	max	0	14	-1173	14	0	14	0	14	0	14	0	14
110			min	0	1	-4833.75	3	0	1	0	1	0	1	0	1
111	Building 2 2x6 Rafter	1	max	0	14	292	3	0	14	0	14	0	14	0	14
112			min	0	1	-95.4	13	0	1	0	1	0	1	0	1
113		2	max	0	14	146	3	0	14	0	14	0	14	230.4	13
114			min	0	1	-135	13	0	1	0	1	0	1	-438	3
115		3	max	0	14	174.6	13	0	14	0	14	0	14	540	13
116			min	0	1	0	1	0	1	0	1	0	1	-584	3

Envelope Member Section Forces (Continued)

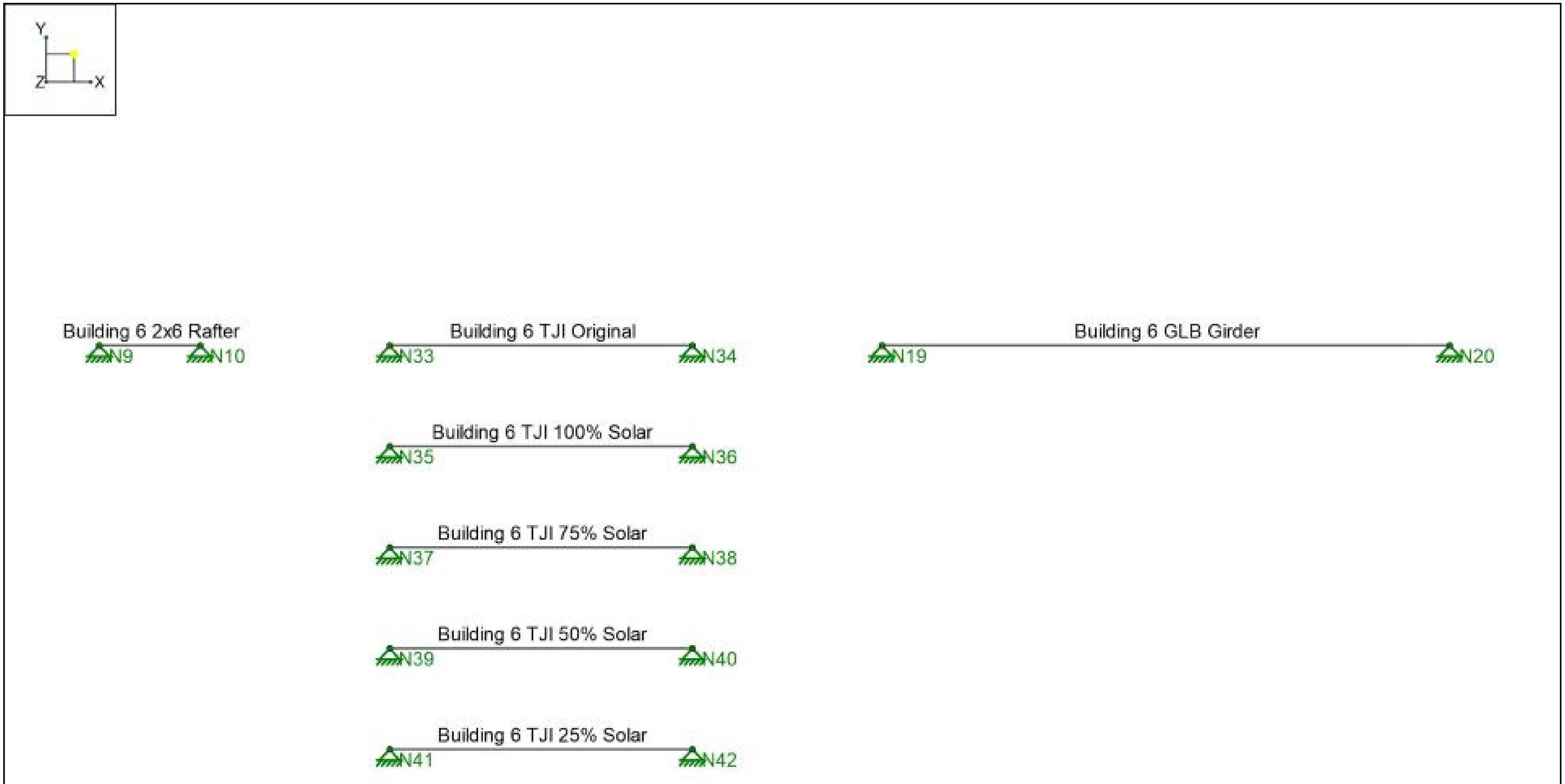
	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
117		4	max	0	14	135	13	0	14	0	14	0	14	230.4	13
118			min	0	1	-146	3	0	1	0	1	0	1	-438	3
119		5	max	0	14	95.4	13	0	14	0	14	0	14	0	14
120			min	0	1	-292	3	0	1	0	1	0	1	0	1
121	Building 2 Joist 50% Solar	1	max	0	14	3156.75	3	0	14	0	14	0	14	0	14
122			min	0	1	1169.55	13	0	1	0	1	0	1	0	1
123		2	max	0	14	1776.75	3	0	14	0	14	0	14	-7409.306	14
124			min	0	1	548.55	13	0	1	0	1	0	1	-21275.719	3
125		3	max	0	14	396.75	3	0	14	0	14	0	14	-9462.487	14
126			min	0	1	-120.75	1	0	1	0	1	0	1	-30648.937	3
127		4	max	0	14	-548.55	14	0	14	0	14	0	14	-6784.425	14
128			min	0	1	-1776.75	3	0	1	0	1	0	1	-24697.688	3
129		5	max	0	14	-1024.65	14	0	14	0	14	0	14	0	14
130			min	0	1	-3950.25	3	0	1	0	1	0	1	0	1
131	Building 2 Joist Original	1	max	0	14	4140	3	0	14	0	14	0	14	0	14
132			min	0	1	952.2	13	0	1	0	1	0	1	0	1
133		2	max	0	14	2070	3	0	14	0	14	0	14	-6159.544	14
134			min	0	1	476.1	13	0	1	0	1	0	1	-26780.625	3
135		3	max	0	14	0	14	0	14	0	14	0	14	-8212.725	14
136			min	0	1	0	1	0	1	0	1	0	1	-35707.5	3
137		4	max	0	14	-476.1	14	0	14	0	14	0	14	-6159.544	14
138			min	0	1	-2070	3	0	1	0	1	0	1	-26780.625	3
139		5	max	0	14	-952.2	14	0	14	0	14	0	14	0	14
140			min	0	1	-4140	3	0	1	0	1	0	1	0	1
141	Building 2 Joist 100% Solar	1	max	0	14	2760	3	0	14	0	14	0	14	0	14
142			min	0	1	1242	13	0	1	0	1	0	1	0	1
143		2	max	0	14	1380	3	0	14	0	14	0	14	-8034.187	14
144			min	0	1	621	13	0	1	0	1	0	1	-17853.75	3
145		3	max	0	14	0	14	0	14	0	14	0	14	-10712.25	14
146			min	0	1	0	1	0	1	0	1	0	1	-23805	3
147		4	max	0	14	-621	14	0	14	0	14	0	14	-8034.187	14
148			min	0	1	-1380	3	0	1	0	1	0	1	-17853.75	3
149		5	max	0	14	-1242	14	0	14	0	14	0	14	0	14
150			min	0	1	-2760	3	0	1	0	1	0	1	0	1
151	Building 2 Joist 75% Solar	1	max	0	14	2859.188	3	0	14	0	14	0	14	0	14
152			min	0	1	1223.888	13	0	1	0	1	0	1	0	1
153		2	max	0	14	1479.188	3	0	14	0	14	0	14	-7877.967	14
154			min	0	1	602.888	13	0	1	0	1	0	1	-18709.242	3
155		3	max	0	14	99.188	3	0	14	0	14	0	14	-10399.809	14
156			min	0	1	-30.188	1	0	1	0	1	0	1	-25515.984	3
157		4	max	0	14	-639.112	14	0	14	0	14	0	14	-7565.527	14
158			min	0	1	-1280.812	3	0	1	0	1	0	1	-20420.227	3
159		5	max	0	14	-1115.212	14	0	14	0	14	0	14	0	14
160			min	0	1	-3454.312	3	0	1	0	1	0	1	0	1
161	Building 2 Joist 25% Solar	1	max	0	14	3623.578	3	0	14	0	14	0	14	0	14
162			min	0	1	1078.987	13	0	1	0	1	0	1	0	1
163		2	max	0	14	2243.578	3	0	14	0	14	0	14	-6628.205	14
164			min	0	1	457.987	13	0	1	0	1	0	1	-25302.111	3
165		3	max	0	14	95.953	3	0	14	0	14	0	14	-8525.166	14
166			min	0	1	-30.187	1	0	1	0	1	0	1	-35391.34	3
167		4	max	0	14	-494.213	14	0	14	0	14	0	14	-6315.764	14
168			min	0	1	-2051.672	3	0	1	0	1	0	1	-26957.303	3
169		5	max	0	14	-970.312	14	0	14	0	14	0	14	0	14
170			min	0	1	-4199.297	3	0	1	0	1	0	1	0	1
171	Building 2 GLB Original Cantilev	1	max	0	14	-8526.375	14	0	14	0	14	0	14	0	14
172			min	0	1	-24545.625	3	0	1	0	1	0	1	0	1
173		2	max	0	14	11099.952	3	0	14	0	14	0	14	59644.112	3
174			min	0	1	3857.452	13	0	1	0	1	0	1	20705.154	13

Envelope Member Section Forces (Continued)

	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
175		3	max	0	14	739.032	3	0	14	0	14	0	14	-6637.195	14
176			min	0	1	256.717	13	0	1	0	1	0	1	-19036.589	3
177		4	max	0	14	-3344.019	14	0	14	0	14	0	14	39998.042	3
178			min	0	1	-9621.887	3	0	1	0	1	0	1	13880.73	13
179		5	max	0	14	19475	3	0	14	0	14	0	14	0	14
180			min	0	1	6765	13	0	1	0	1	0	1	0	1
181	Building 2 GLB Original Simply S	1	max	0	14	17841.75	3	0	14	0	14	0	14	0	14
182			min	0	1	9154.8	13	0	1	0	1	0	1	0	1
183		2	max	0	14	8684.625	3	0	14	0	14	0	14	-91348.481	14
184			min	0	1	4435.65	13	0	1	0	1	0	1	-177923.484	3
185		3	max	0	14	-283.5	14	0	14	0	14	0	14	-121599.225	14
186			min	0	1	-472.5	3	0	1	0	1	0	1	-236900.062	3
187		4	max	0	14	-4552.65	14	0	14	0	14	0	14	-89559.731	14
188			min	0	1	-8879.625	3	0	1	0	1	0	1	-174942.234	3
189		5	max	0	14	-9271.8	14	0	14	0	14	0	14	0	14
190			min	0	1	-18036.75	3	0	1	0	1	0	1	0	1

Existing Building Framing RISA Graphics and Report:

Buildings 3, 4, & 6



	ARCE Senior Project (Existing Framing)	SK-1
ROK		
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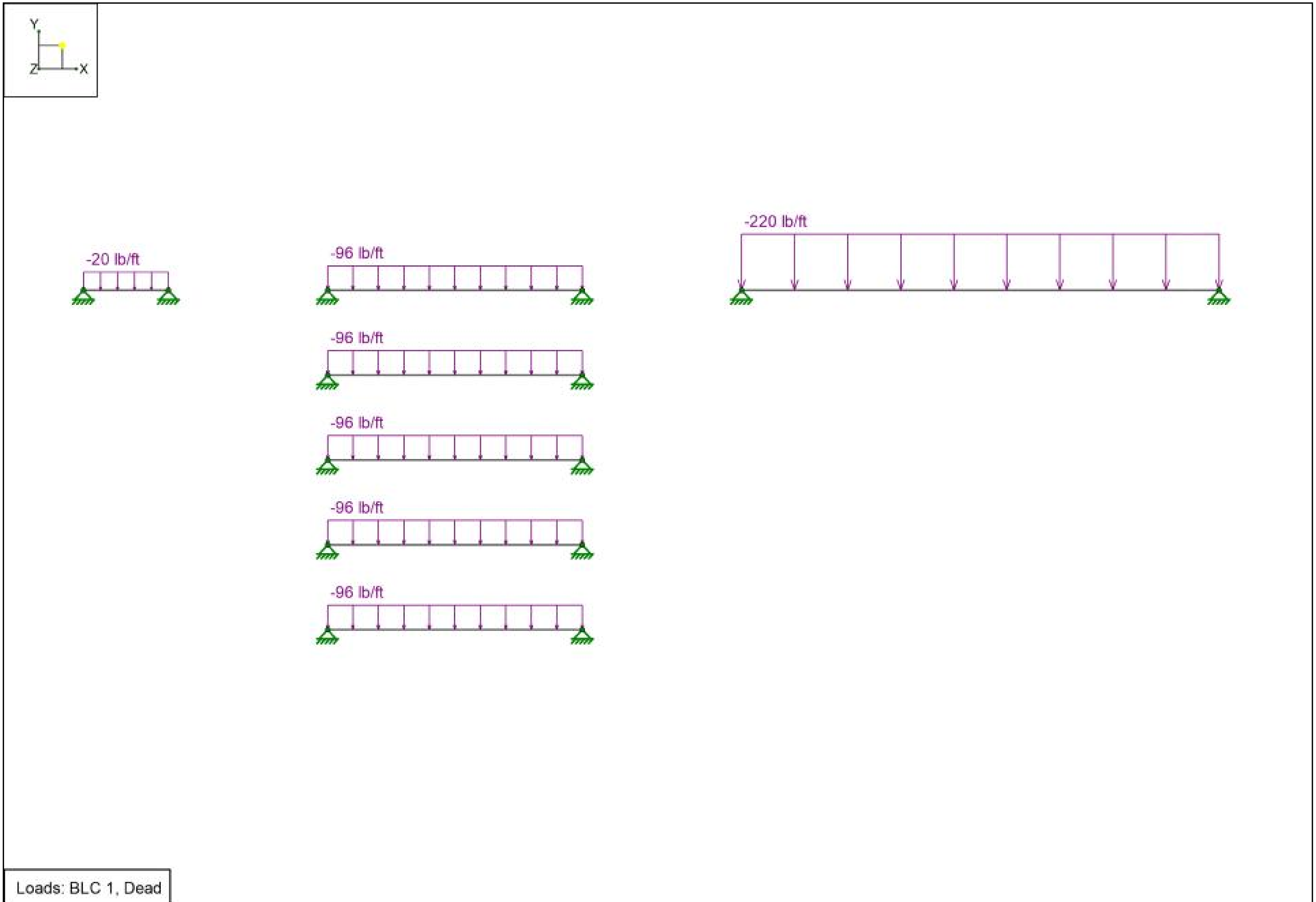

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ROK		
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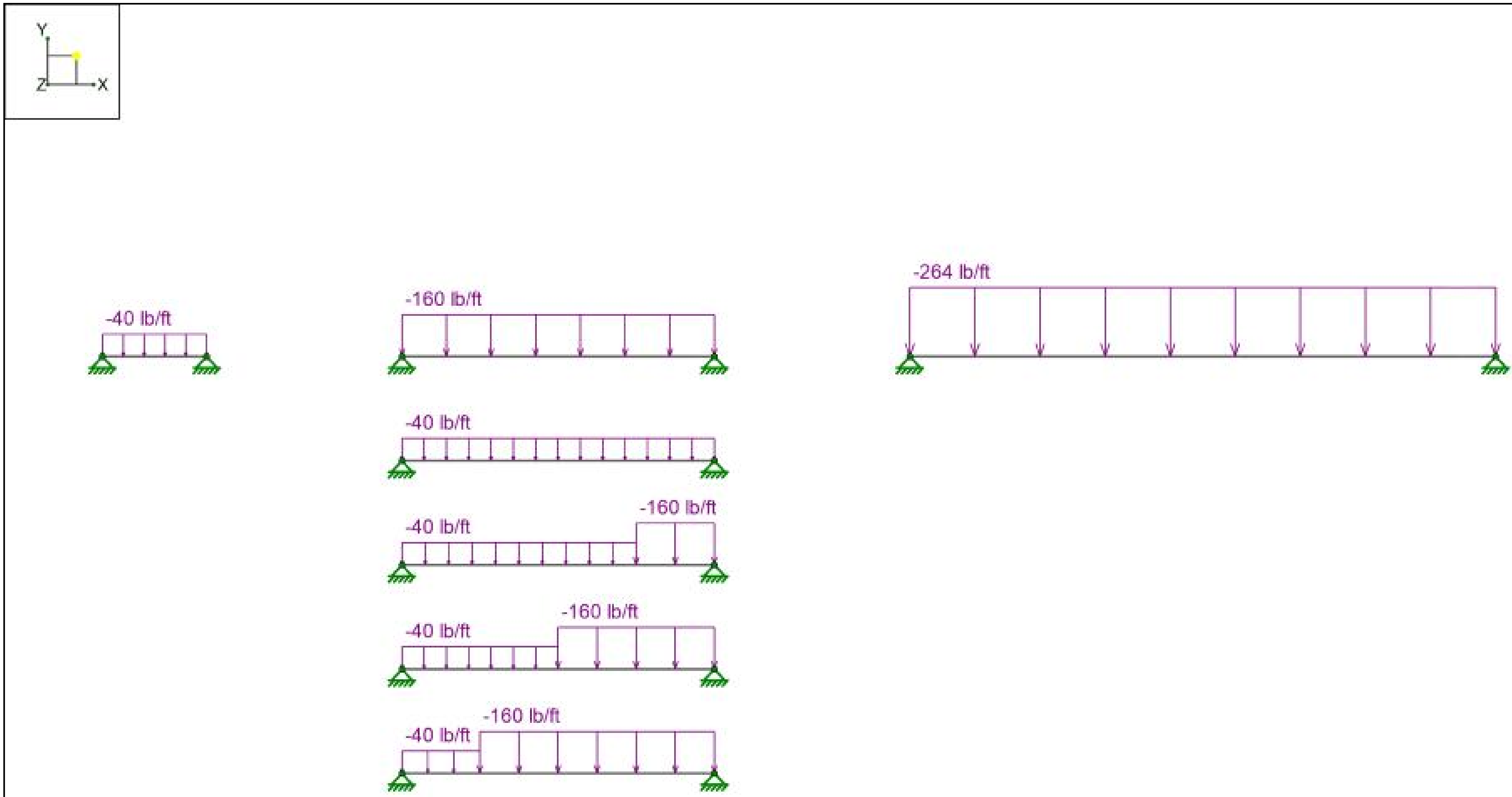

Loads: BLC 2, Roof Live

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ROK		
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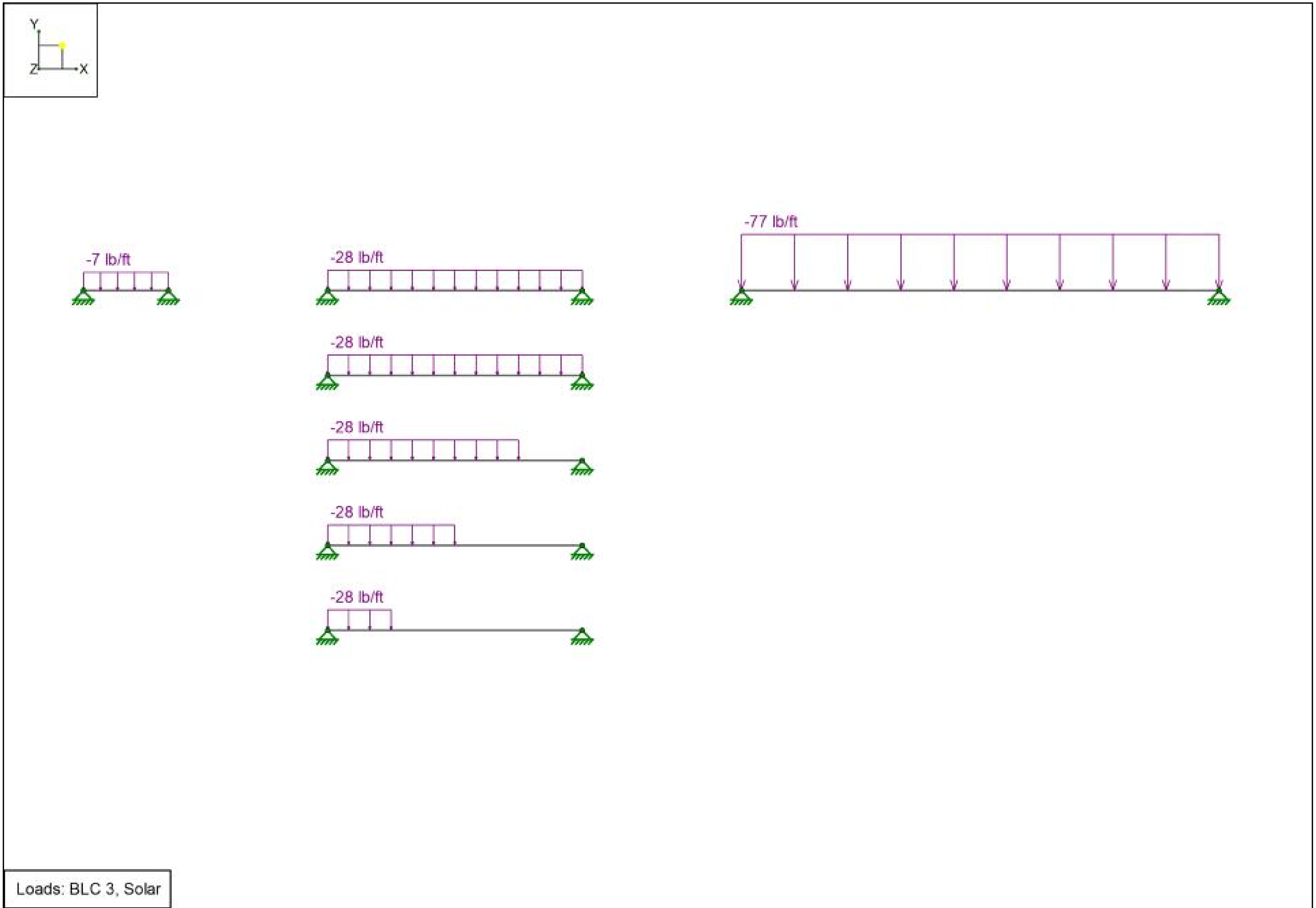

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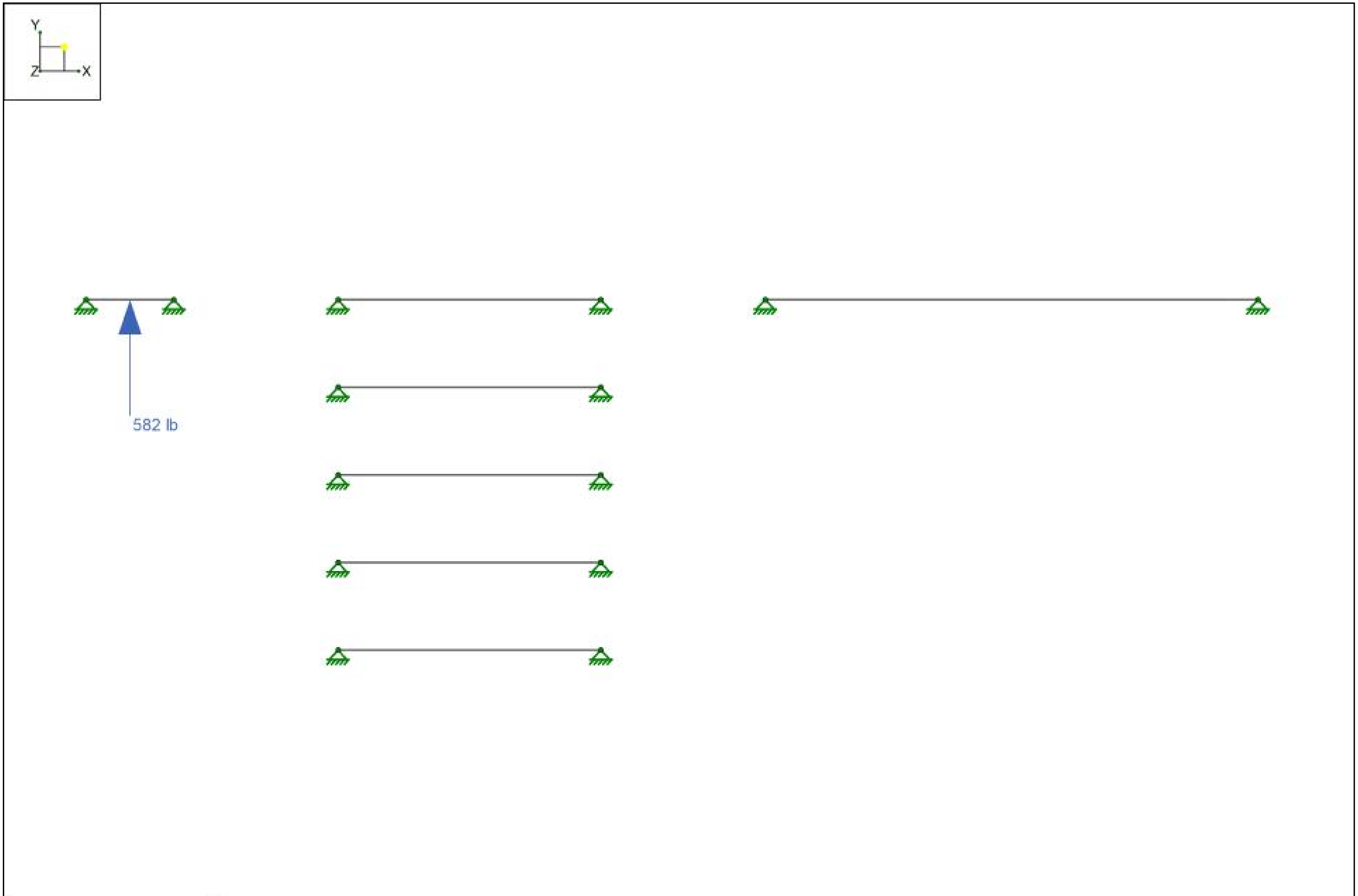

Loads: BLC 4, Wind Uplift

	ARCE Senior Project (Existing Framing)	SK-5
ROK		
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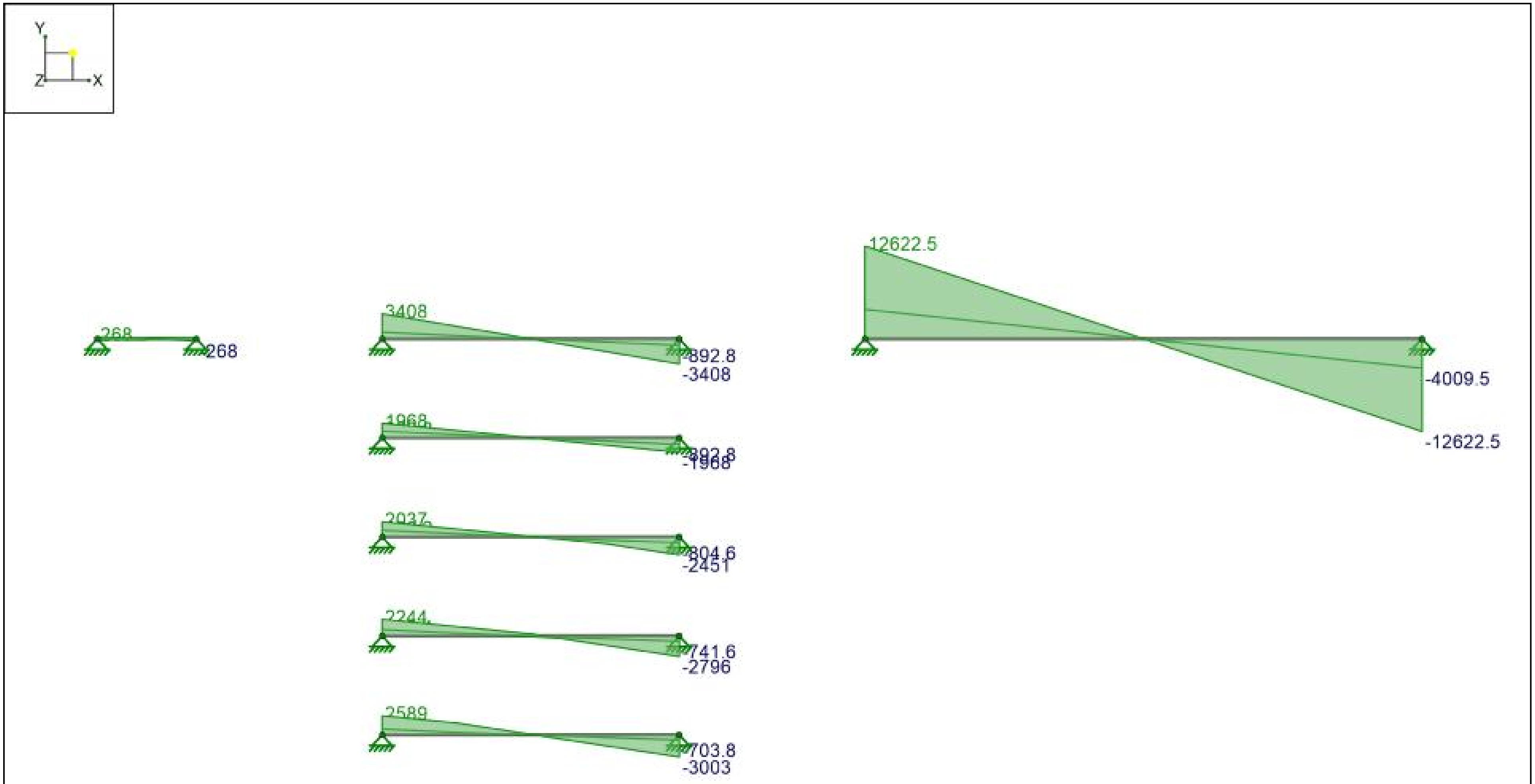

Envelope Only Solution
Member y Shear Forces (lbs) (Enveloped)

	ARCE Senior Project (Existing Framing)	SK-6
ROK		
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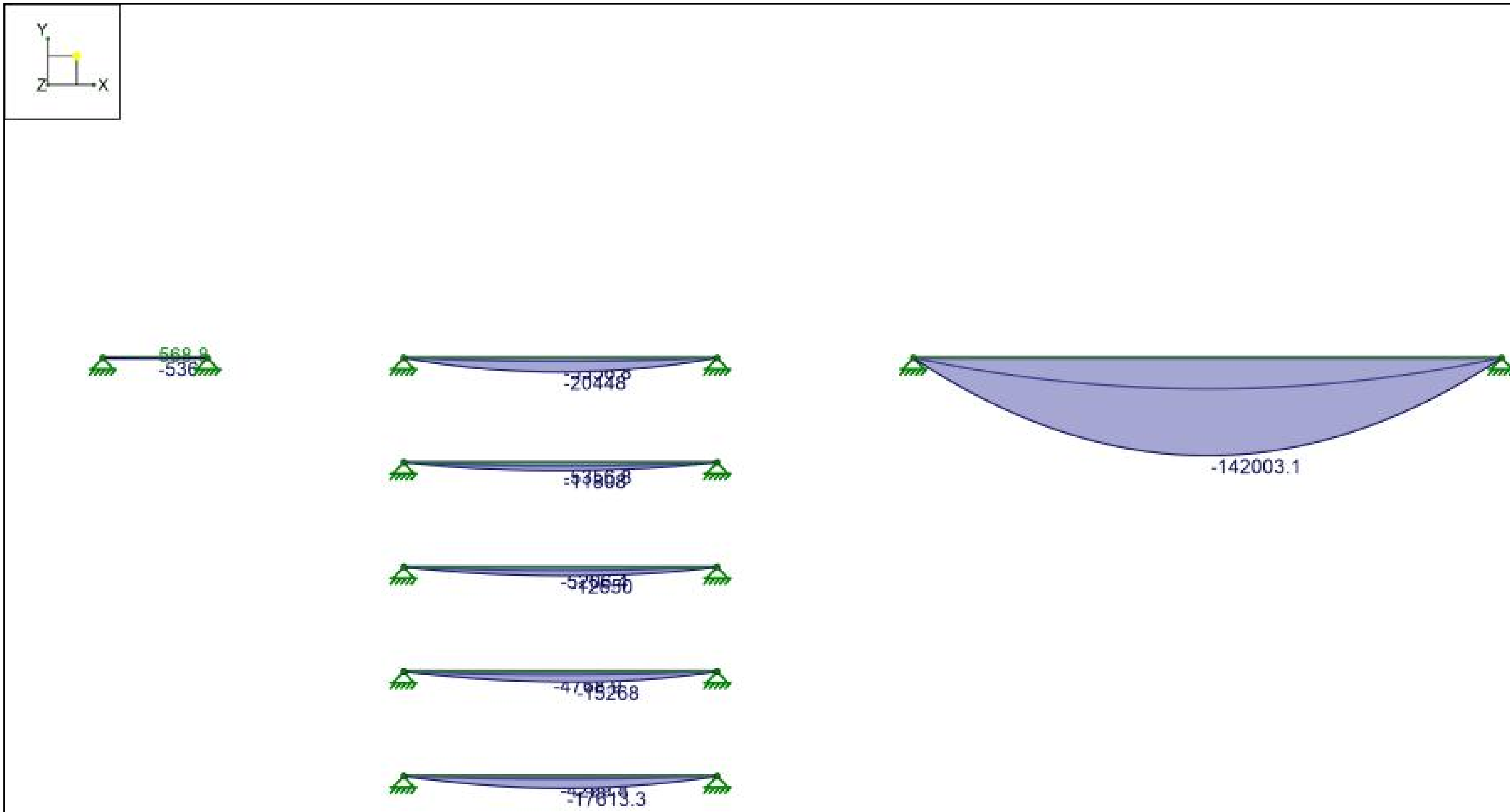

Envelope Only Solution
Member z Bending Moments (lb-ft) (Enveloped)

	ARCE Senior Project (Existing Framing)	SK-7
ROK		
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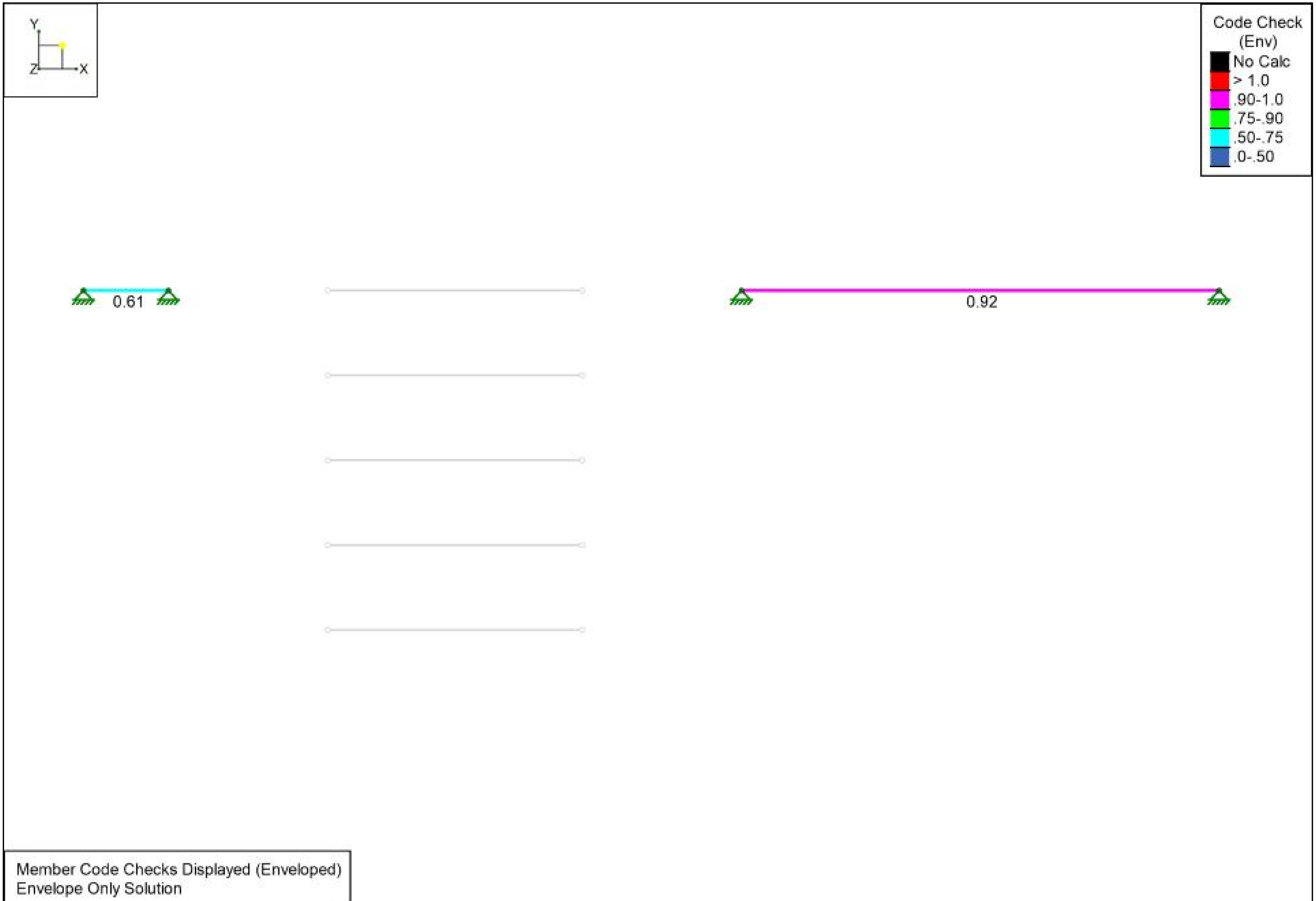

	ARCE Senior Project (Existing Framing)	SK-8
ROK		
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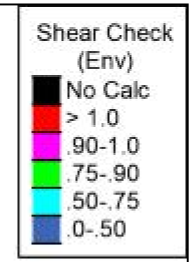
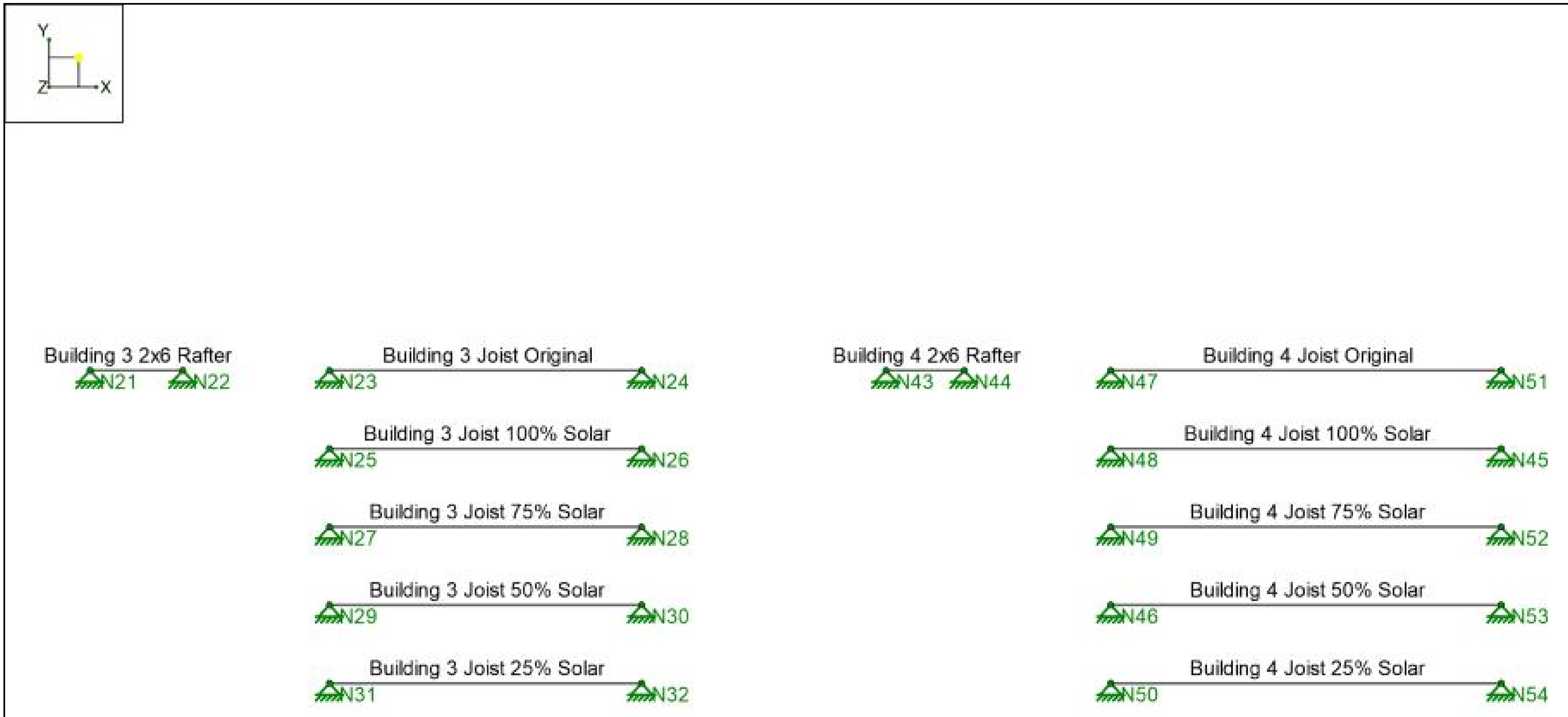


Member Shear Checks Displayed (Enveloped)
Envelope Only Solution

	ARCE Senior Project (Existing Framing)	SK-9
ROK		
		Senior Project (Existing Framing).r3d



	ARCE Senior Project (Existing Framing)	SK-10
ROK		
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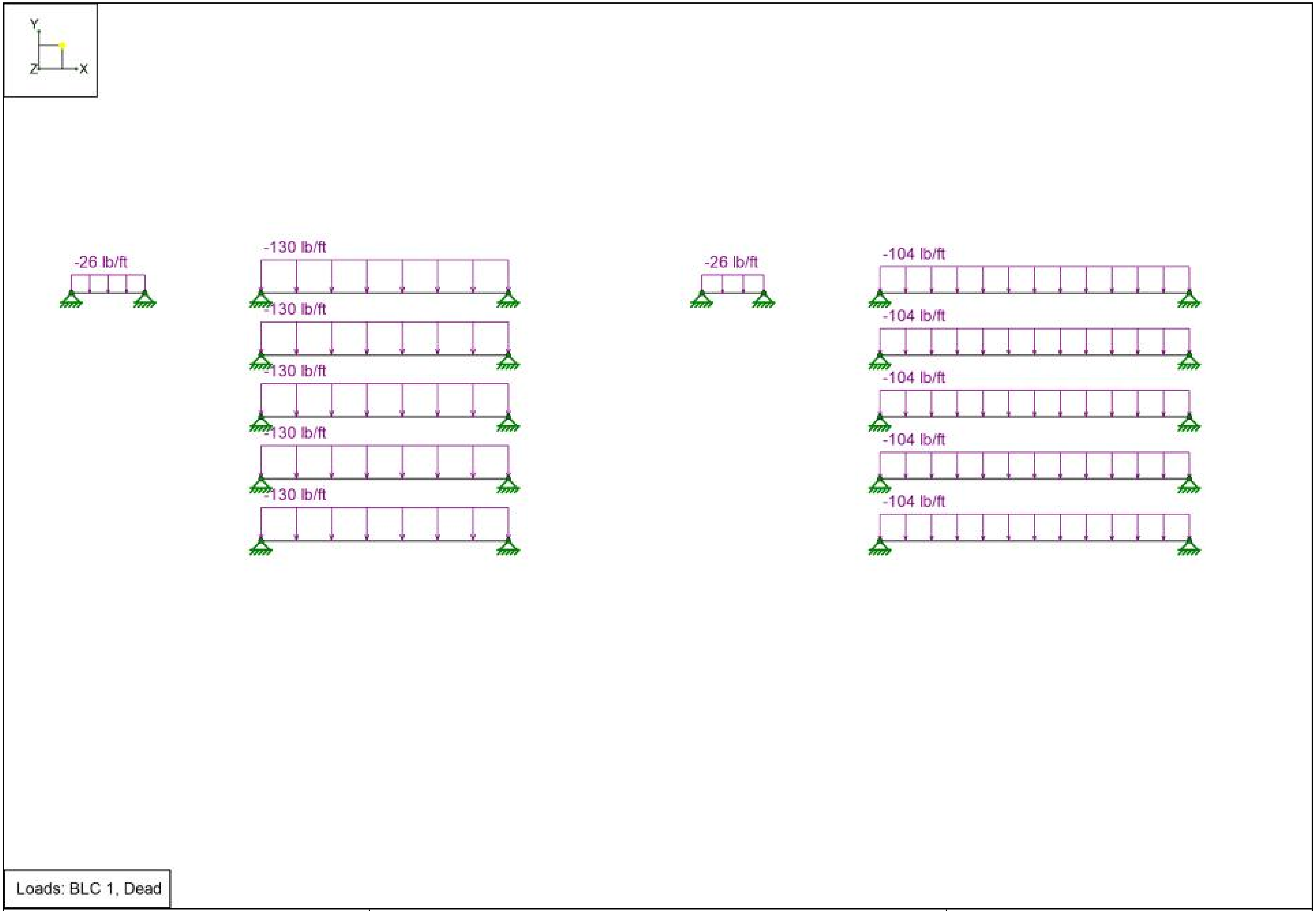
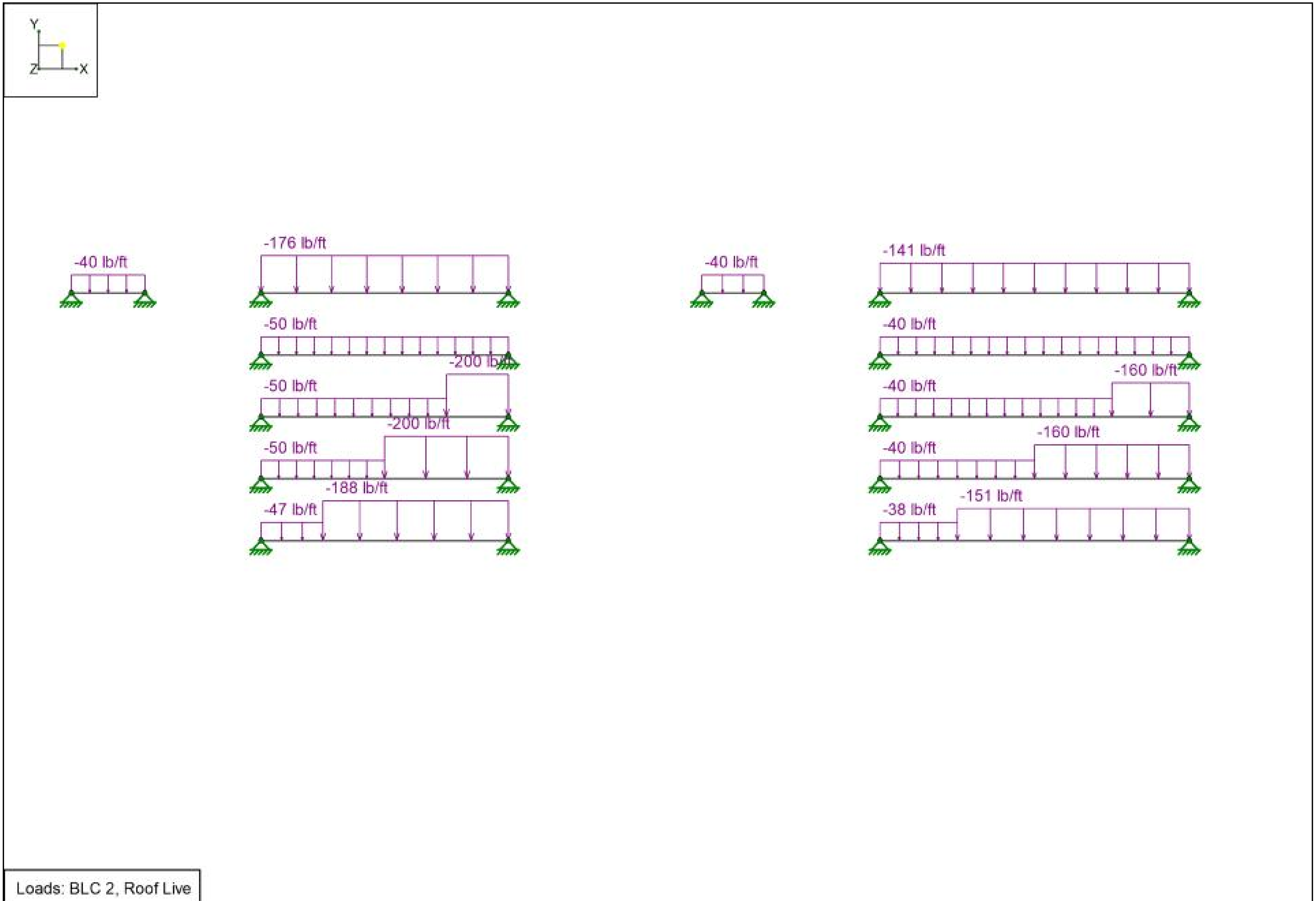


	ARCE Senior Project (Existing Framing)	SK-11
ROK		
		Senior Project (Existing Framing).r3d



	ARCE Senior Project (Existing Framing)	SK-12
ROK		
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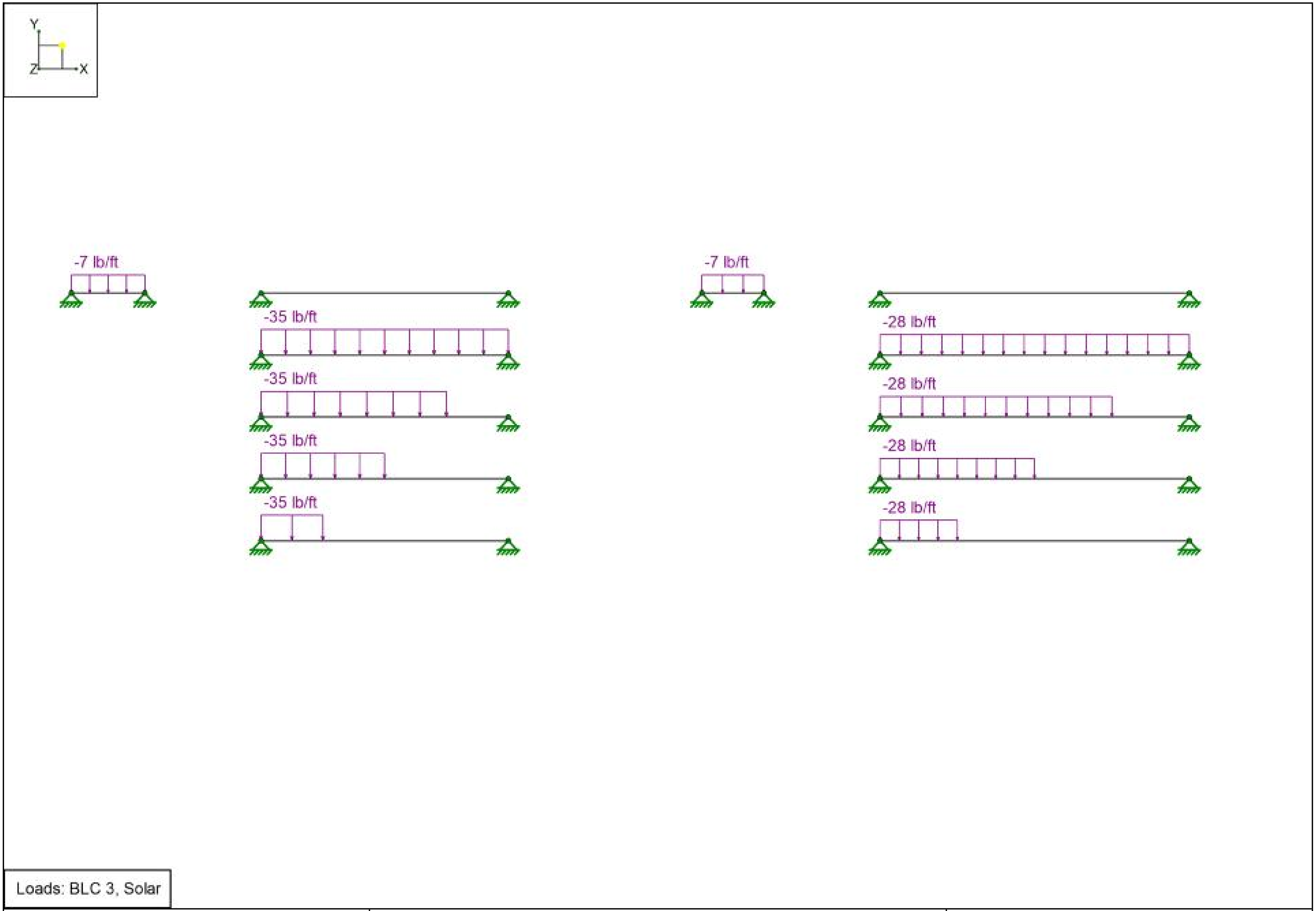
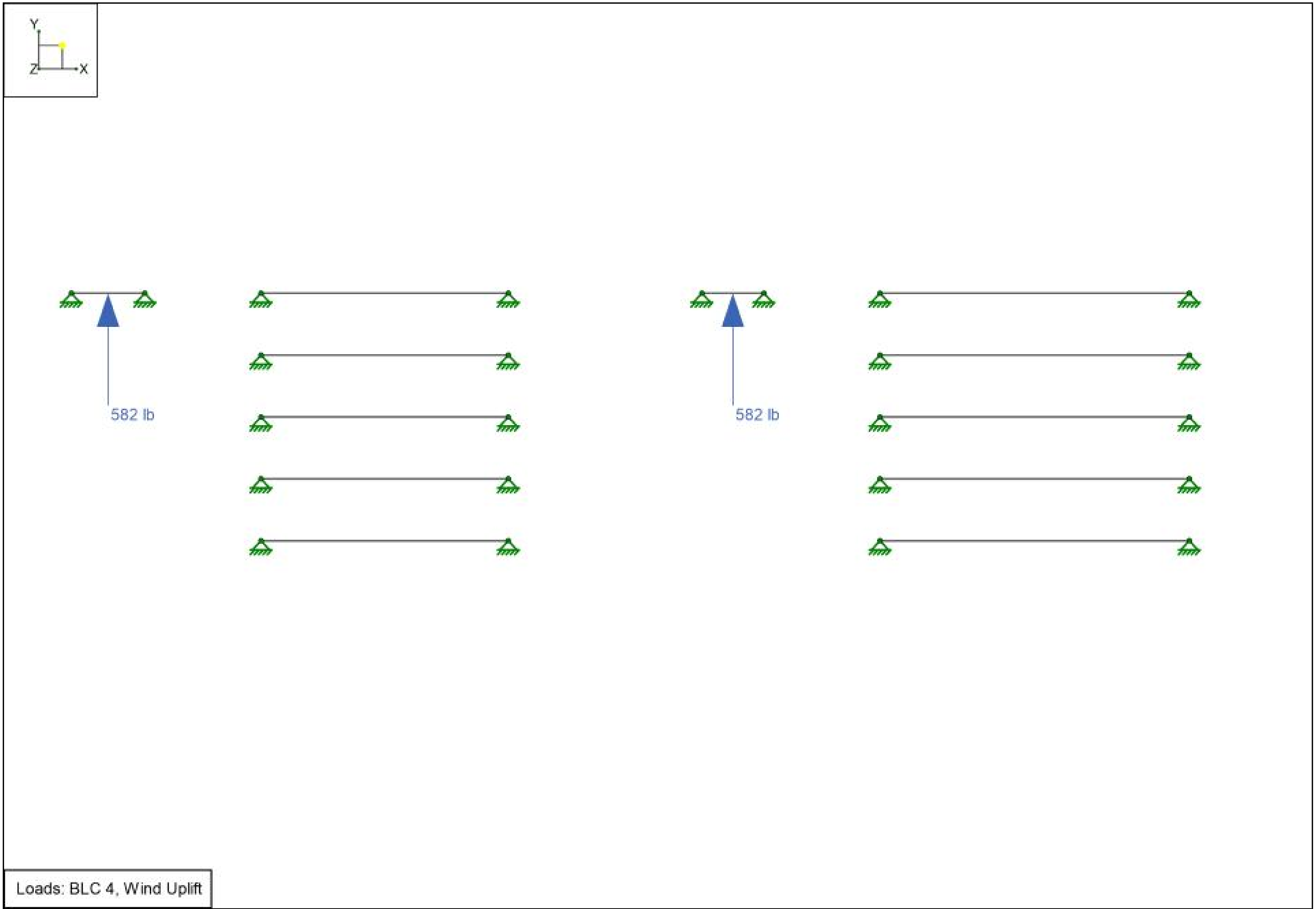
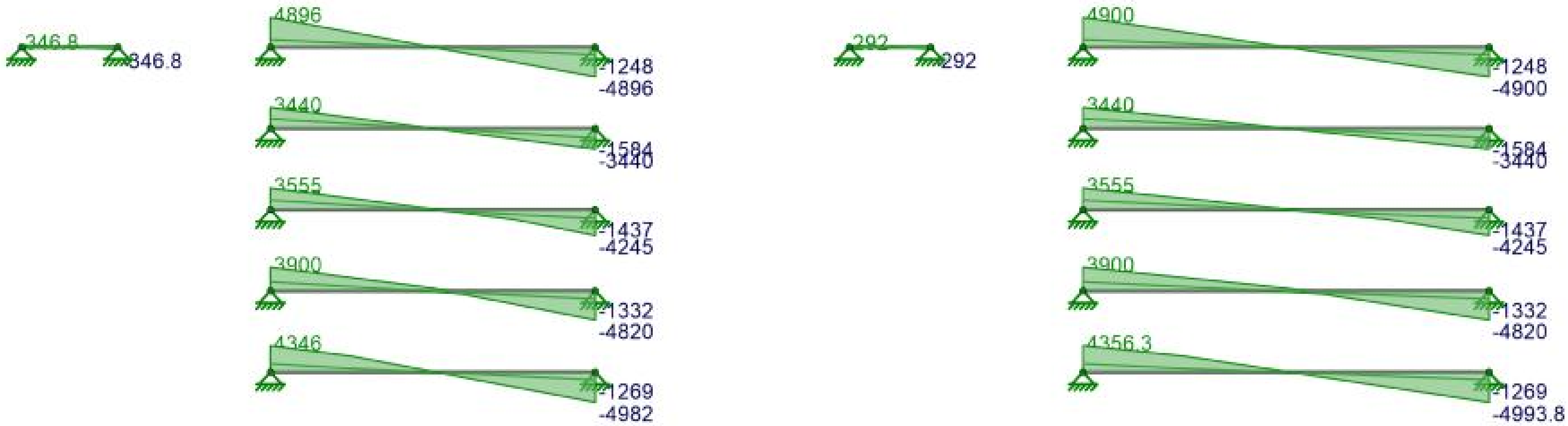


	ARCE Senior Project (Existing Framing)	SK-13
ROK		
		Senior Project (Existing Framing).r3d

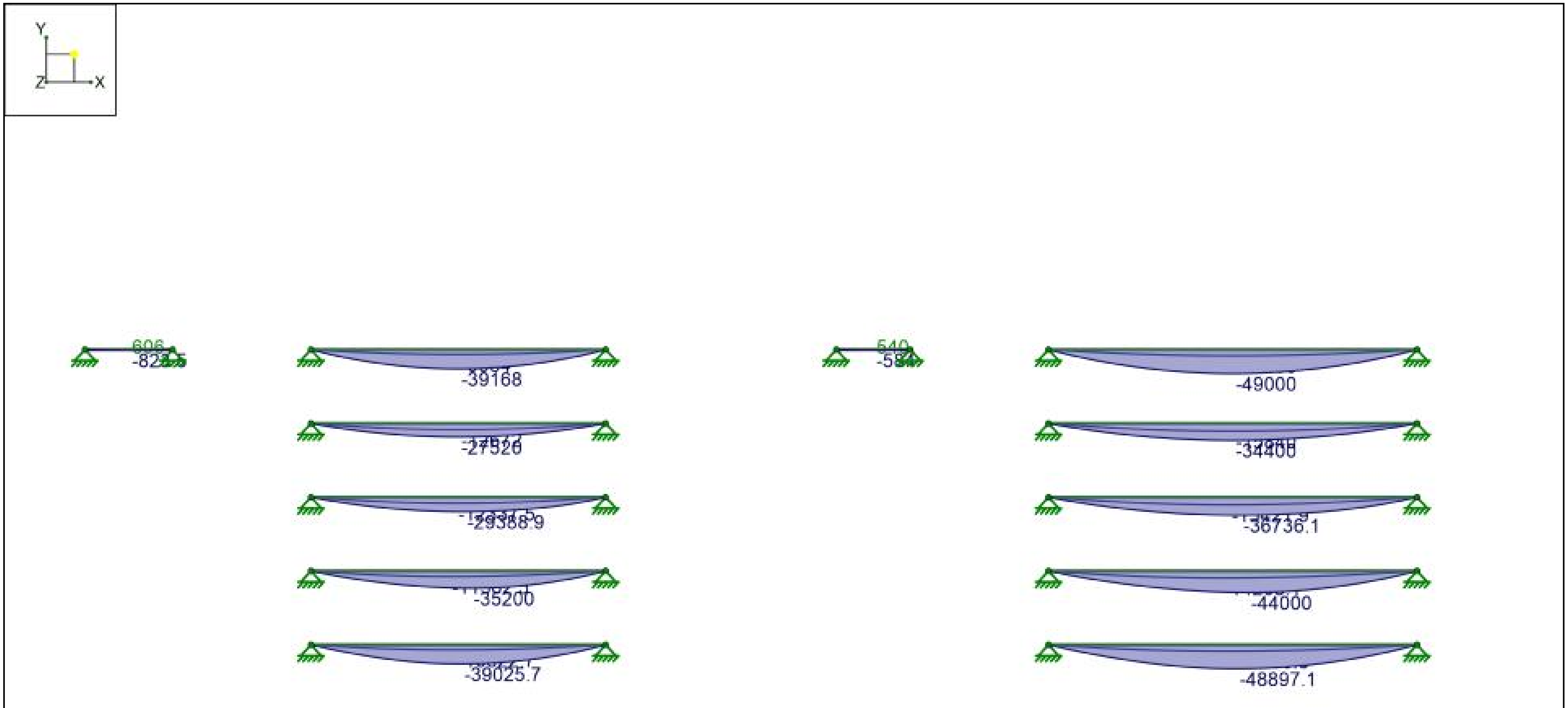


	ARCE Senior Project (Existing Framing)	SK-14
ROK		
		Senior Project (Existing Framing).r3d



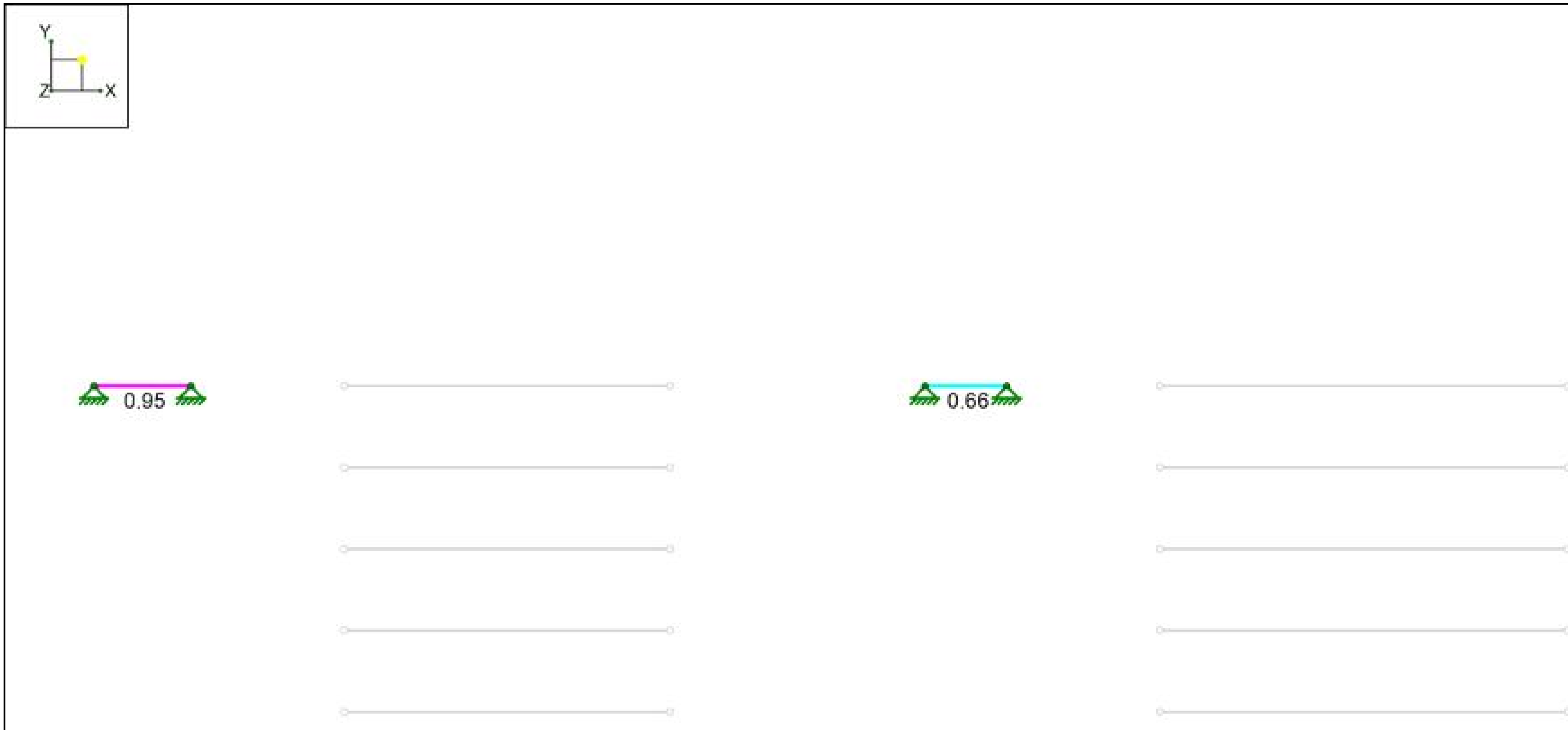
Envelope Only Solution
Member y Shear Forces (lbs) (Enveloped)

	ARCE Senior Project (Existing Framing)	SK-15
ROK		
		Senior Project (Existing Framing).r3d



Envelope Only Solution
Member z Bending Moments (lb-ft) (Enveloped)

	ARCE Senior Project (Existing Framing)	SK-16
ROK		
		Senior Project (Existing Framing).r3d

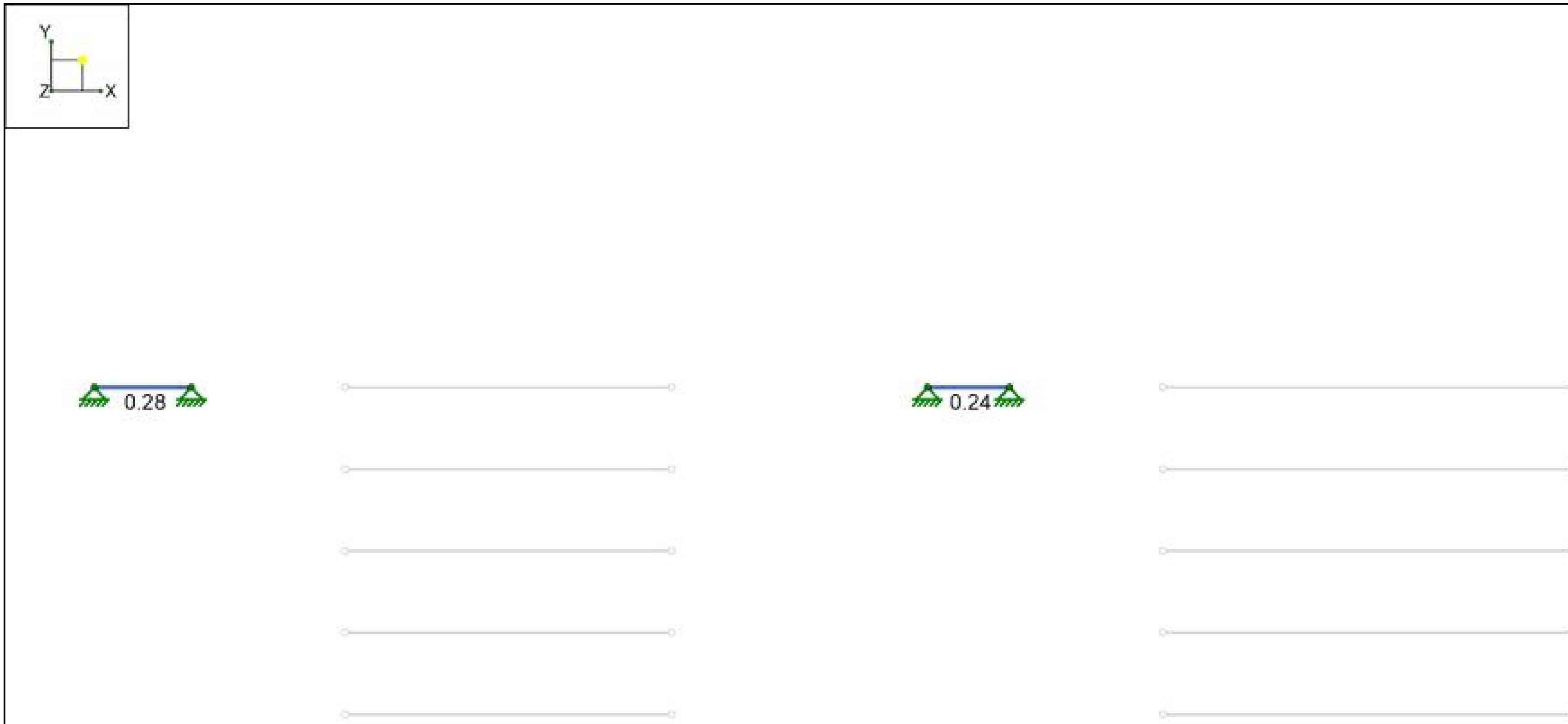


Code Check (Env)

No Calc	
> 1.0	
.90-1.0	
.75-.90	
.50-.75	
.0-.50	

Member Code Checks Displayed (Enveloped)
Envelope Only Solution

	ARCE Senior Project (Existing Framing)	SK-17
ROK		
		Senior Project (Existing Framing).r3d



Shear Check
(Env)
No Calc
> 1.0
.90-1.0
.75-.90
.50-.75
.0-.50

Member Shear Checks Displayed (Enveloped)
Envelope Only Solution

	ARCE Senior Project (Existing Framing)	SK-18
ROK		
		Senior Project (Existing Framing).r3d

Wood Material Properties

	Label	Type	Database	Species	Grade	Cm	Emod	Nu	Therm. Coeff. [1e^5°F^{-1}]	Density [k/ft^3]
1	DF	Solid Sawn	Visually Graded	Douglas Fir-Larch	No.2		1	0.3	0.3	0.035
2	SP	Solid Sawn	Visually Graded	Douglas Fir-Larch	Select Structural		1	0.3	0.3	0.035
3	HF	Solid Sawn	Visually Graded	Hem-Fir	No.1		1	0.3	0.3	0.035
4	SPF	Solid Sawn	Visually Graded	Spruce-Pine-fir	No.1		1	0.3	0.3	0.035
5	24F-1.8E DF Balanced	Glulam	CSA Table 6.3	24f_E_DFL	na		1	0.3	0.3	0.035
6	24F-1.8E DF Unbalanced	Glulam	CSA Table 6.3	24f_E_DFL	na		1	0.3	0.3	0.035
7	24F-1.8E SP Balanced	Glulam	CSA Table 6.3	24f_E_DFL	na		1	0.3	0.3	0.035
8	24F-1.8E SP Unbalanced	Glulam	CSA Table 6.3	24f_E_DFL	na		1	0.3	0.3	0.035
9	1.3E-1600F_VERSALAM	SCL	Boise Cascade	1.3E-1600F_VERSALAM	na		1	0.3	0.3	0.035
10	1.35E LSL_SolidStart	SCL	Louisiana Pacific	1.35E LSL_SolidStart	na		1	0.3	0.3	0.035
11	1.3E_RIGIDLAM LVL	SCL	Roseburg Forest Products	1.3E_RIGIDLAM LVL	na		1	0.3	0.3	0.035
12	2.0E_DF Parallam PSL	SCL	TrusJoist	2.0E_DF Parallam PSL	na		1	0.3	0.3	0.035
13	LVL_PRL_1.5E_2250F	Custom	N/A	LVL_PRL_1.5E_2250F	na		1	0.3	0.3	0.035
14	LVL_Microlam_1.9E_2600F	Custom	N/A	LVL_Microllam_1.9E_2600F	na		1	0.3	0.3	0.035
15	PSL_Parallam_2.0E_2900F	Custom	N/A	PSL_Parallam_2.0E_2900F	na		1	0.3	0.3	0.035
16	LSL_TimberStrand_1.55E_2325F	Custom	N/A	LSL_TimberStrand_1.55E_2325F	na		1	0.3	0.3	0.035

Wood Design Parameters

	Label	Shape	Length [ft]	le-bend top [ft]	Cr	y sway	z sway
1	Building 6 2x6 Rafter	2X6	8	Lbyy			
2	Building 6 GLB Girder	6.75X19.5FS	45	Lbyy			
3	Building 3 2x6 Rafter	2X6	9.5	Lbyy			
4	Building 4 2x6 Rafter	2X6	8	Lbyy			

Basic Load Cases

	BLC Description	Category	Point	Distributed
1	Dead	DL		19
2	Roof Live	RLL		28
3	Solar	DL		17
4	Wind Uplift	WL	3	
5	Wind Down	WL		

Load Combinations

	Description	Solve	PDelta	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
1	ASCE ASD 1	Yes	Y	DL	1										
2	ASCE ASD 2	Yes	Y	DL	1	LL	1	LLS	1						
3	ASCE ASD 3 (a)	Yes	Y	DL	1	RLL	1								
4	ASCE ASD 4 (a)	Yes	Y	DL	1	LL	0.75	LLS	0.75	RLL	0.75				
5	ASCE ASD 5 (a)	Yes	Y	DL	1	4	0.6								
6	ASCE ASD 5 (a)	Yes	Y	DL	1	5	0.6								
7	ASCE ASD 6 (a)	Yes	Y	DL	1	4	0.45	LL	0.75	LLS	0.75	RLL	0.75		
8	ASCE ASD 6 (a)	Yes	Y	DL	1	5	0.45	LL	0.75	LLS	0.75	RLL	0.75		
9	ASCE ASD 6 (b)	Yes	Y	DL	1	4	0.45	LL	0.75	LLS	0.75	SL	0.75	SLN	0.75
10	ASCE ASD 6 (b)	Yes	Y	DL	1	5	0.45	LL	0.75	LLS	0.75	SL	0.75	SLN	0.75
11	ASCE ASD 6 (c)	Yes	Y	DL	1	4	0.45	LL	0.75	LLS	0.75	RL	0.75		
12	ASCE ASD 6 (c)	Yes	Y	DL	1	5	0.45	LL	0.75	LLS	0.75	RL	0.75		
13	ASCE ASD 7	Yes	Y	DL	0.6	4	0.6								
14	ASCE ASD 7	Yes	Y	DL	0.6	5	0.6								

Envelope Wood Code Checks

	Member	Shape	Code Check	Loc[ft]	LC	Shear Check	Loc[ft]	Dir	LC	Fc' [ksi]	Ft' [ksi]	Fb1' [ksi]	Fb2' [ksi]	Fv' [ksi]	RB	CL	CP	Eqn
1	Building 6 2x6 Rafter	2X6	0.607	4	3	0.217	8	y	3	0.116	0.934	1.401	1.682	0.225	15.319	0.958	0.062	3.9-3
2	Building 6 GLB Girder	6.75X19.5FS	0.921	22.5	3	0.397	45	y	3	0.126	2.774	4.327	1.94	0.363	15.202	0.78	0.023	3.9-3
3	Building 3 2x6 Rafter	2X6	0.948	4.75	3	0.28	9.5	y	3	0.082	0.934	1.379	1.682	0.225	16.693	0.943	0.044	3.9-3
4	Building 4 2x6 Rafter	2X6	0.662	4	3	0.236	8	y	3	0.116	0.934	1.401	1.682	0.225	15.319	0.958	0.062	3.9-3

Envelope Member Section Forces

	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
1	Building 6 2x6 Rafter	1	max	0	14	268	3	0	14	0	14	0	14	0	14
2			min	0	1	-109.8	13	0	1	0	1	0	1	0	1
3		2	max	0	14	134	3	0	14	0	14	0	14	252	13
4			min	0	1	-142.2	13	0	1	0	1	0	1	-402	3
5		3	max	0	14	174.6	13	0	14	0	14	0	14	568.8	13
6			min	0	1	0	1	0	1	0	1	0	1	-536	3
7		4	max	0	14	142.2	13	0	14	0	14	0	14	252	13
8			min	0	1	-134	3	0	1	0	1	0	1	-402	3
9		5	max	0	14	109.8	13	0	14	0	14	0	14	0	14
10			min	0	1	-268	3	0	1	0	1	0	1	0	1
11	Building 6 GLB Girder	1	max	0	14	12622.5	3	0	14	0	14	0	14	0	14
12			min	0	1	4009.5	13	0	1	0	1	0	1	0	1
13		2	max	0	14	6311.25	3	0	14	0	14	0	14	-33830.156	14
14			min	0	1	2004.75	13	0	1	0	1	0	1	-106502.344	3
15		3	max	0	14	0	14	0	14	0	14	0	14	-45106.875	14
16			min	0	1	0	1	0	1	0	1	0	1	-142003.125	3
17		4	max	0	14	-2004.75	14	0	14	0	14	0	14	-33830.156	14
18			min	0	1	-6311.25	3	0	1	0	1	0	1	-106502.344	3
19		5	max	0	14	-4009.5	14	0	14	0	14	0	14	0	14
20			min	0	1	-12622.5	3	0	1	0	1	0	1	0	1
21	Building 3 2x6 Rafter	1	max	0	14	346.75	3	0	14	0	14	0	14	0	14
22			min	0	1	-80.55	13	0	1	0	1	0	1	0	1
23		2	max	0	14	173.375	3	0	14	0	14	0	14	247.148	13
24			min	0	1	-127.575	13	0	1	0	1	0	1	-617.648	3
25		3	max	0	14	174.6	5	0	14	0	14	0	14	605.981	13
26			min	0	1	0	1	0	1	0	1	0	1	-823.531	3
27		4	max	0	14	127.575	13	0	14	0	14	0	14	247.148	13
28			min	0	1	-173.375	3	0	1	0	1	0	1	-617.648	3
29		5	max	0	14	80.55	13	0	14	0	14	0	14	0	14
30			min	0	1	-346.75	3	0	1	0	1	0	1	0	1
31	Building 3 Joist Original	1	max	0	14	4896	3	0	14	0	14	0	14	0	14
32			min	0	1	1248	13	0	1	0	1	0	1	0	1
33		2	max	0	14	2448	3	0	14	0	14	0	14	-7488	14
34			min	0	1	624	13	0	1	0	1	0	1	-29376	3
35		3	max	0	14	0	14	0	14	0	14	0	14	-9984	14
36			min	0	1	0	1	0	1	0	1	0	1	-39168	3
37		4	max	0	14	-624	14	0	14	0	14	0	14	-7488	14
38			min	0	1	-2448	3	0	1	0	1	0	1	-29376	3
39		5	max	0	14	-1248	14	0	14	0	14	0	14	0	14
40			min	0	1	-4896	3	0	1	0	1	0	1	0	1
41	Building 3 Joist 100% Solar	1	max	0	14	3440	3	0	14	0	14	0	14	0	14
42			min	0	1	1584	13	0	1	0	1	0	1	0	1
43		2	max	0	14	1720	3	0	14	0	14	0	14	-9504	14
44			min	0	1	792	13	0	1	0	1	0	1	-20640	3
45		3	max	0	14	0	14	0	14	0	14	0	14	-12672	14
46			min	0	1	0	1	0	1	0	1	0	1	-27520	3
47		4	max	0	14	-792	14	0	14	0	14	0	14	-9504	14
48			min	0	1	-1720	3	0	1	0	1	0	1	-20640	3
49		5	max	0	14	-1584	14	0	14	0	14	0	14	0	14
50			min	0	1	-3440	3	0	1	0	1	0	1	0	1
51	Building 3 Joist 75% Solar	1	max	0	14	3555	3	0	14	0	14	0	14	0	14
52			min	0	1	1563	13	0	1	0	1	0	1	0	1
53		2	max	0	14	1835	3	0	14	0	14	0	14	-9336	14
54			min	0	1	771	13	0	1	0	1	0	1	-21560	3
55		3	max	0	14	115	3	0	14	0	14	0	14	-12336	14
56			min	0	1	-35	1	0	1	0	1	0	1	-29360	3
57		4	max	0	14	-813	14	0	14	0	14	0	14	-9000	14
58			min	0	1	-1605	3	0	1	0	1	0	1	-23400	3

Envelope Member Section Forces (Continued)

	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
59		5	max	0	14	-1437	14	0	14	0	14	0	14	0	14
60			min	0	1	-4245	3	0	1	0	1	0	1	0	1
61	Building 3 Joist 50% Solar	1	max	0	14	3900	3	0	14	0	14	0	14	0	14
62			min	0	1	1500	13	0	1	0	1	0	1	0	1
63		2	max	0	14	2180	3	0	14	0	14	0	14	-8832	14
64			min	0	1	708	13	0	1	0	1	0	1	-24320	3
65		3	max	0	14	460	3	0	14	0	14	0	14	-11328	14
66			min	0	1	-140	1	0	1	0	1	0	1	-34880	3
67		4	max	0	14	-708	14	0	14	0	14	0	14	-8160	14
68			min	0	1	-2180	3	0	1	0	1	0	1	-28000	3
69		5	max	0	14	-1332	14	0	14	0	14	0	14	0	14
70			min	0	1	-4820	3	0	1	0	1	0	1	0	1
71	Building 3 Joist 25% Solar	1	max	0	14	4346	3	0	14	0	14	0	14	0	14
72			min	0	1	1395	13	0	1	0	1	0	1	0	1
73		2	max	0	14	2650	3	0	14	0	14	0	14	-7992	14
74			min	0	1	603	13	0	1	0	1	0	1	-27984	3
75		3	max	0	14	106	3	0	14	0	14	0	14	-10320	14
76			min	0	1	-35	1	0	1	0	1	0	1	-39008	3
77		4	max	0	14	-645	14	0	14	0	14	0	14	-7656	14
78			min	0	1	-2438	3	0	1	0	1	0	1	-29680	3
79		5	max	0	14	-1269	14	0	14	0	14	0	14	0	14
80			min	0	1	-4982	3	0	1	0	1	0	1	0	1
81	Building 4 2x6 Rafter	1	max	0	14	292	3	0	14	0	14	0	14	0	14
82			min	0	1	-95.4	13	0	1	0	1	0	1	0	1
83		2	max	0	14	146	3	0	14	0	14	0	14	230.4	13
84			min	0	1	-135	13	0	1	0	1	0	1	-438	3
85		3	max	0	14	174.6	13	0	14	0	14	0	14	540	13
86			min	0	1	0	1	0	1	0	1	0	1	-584	3
87		4	max	0	14	135	13	0	14	0	14	0	14	230.4	13
88			min	0	1	-146	3	0	1	0	1	0	1	-438	3
89		5	max	0	14	95.4	13	0	14	0	14	0	14	0	14
90			min	0	1	-292	3	0	1	0	1	0	1	0	1
91	Building 4 Joist 50% Solar	1	max	0	14	3900	3	0	14	0	14	0	14	0	14
92			min	0	1	1500	13	0	1	0	1	0	1	0	1
93		2	max	0	14	2180	3	0	14	0	14	0	14	-11040	14
94			min	0	1	708	13	0	1	0	1	0	1	-30400	3
95		3	max	0	14	460	3	0	14	0	14	0	14	-14160	14
96			min	0	1	-140	1	0	1	0	1	0	1	-43600	3
97		4	max	0	14	-708	14	0	14	0	14	0	14	-10200	14
98			min	0	1	-2180	3	0	1	0	1	0	1	-35000	3
99		5	max	0	14	-1332	14	0	14	0	14	0	14	0	14
100			min	0	1	-4820	3	0	1	0	1	0	1	0	1
101	Building 4 Joist Original	1	max	0	14	4900	3	0	14	0	14	0	14	0	14
102			min	0	1	1248	13	0	1	0	1	0	1	0	1
103		2	max	0	14	2450	3	0	14	0	14	0	14	-9360	14
104			min	0	1	624	13	0	1	0	1	0	1	-36750	3
105		3	max	0	14	0	14	0	14	0	14	0	14	-12480	14
106			min	0	1	0	1	0	1	0	1	0	1	-49000	3
107		4	max	0	14	-624	14	0	14	0	14	0	14	-9360	14
108			min	0	1	-2450	3	0	1	0	1	0	1	-36750	3
109		5	max	0	14	-1248	14	0	14	0	14	0	14	0	14
110			min	0	1	-4900	3	0	1	0	1	0	1	0	1
111	Building 4 Joist 100% Solar	1	max	0	14	3440	3	0	14	0	14	0	14	0	14
112			min	0	1	1584	13	0	1	0	1	0	1	0	1
113		2	max	0	14	1720	3	0	14	0	14	0	14	-11880	14
114			min	0	1	792	13	0	1	0	1	0	1	-25800	3
115		3	max	0	14	0	14	0	14	0	14	0	14	-15840	14
116			min	0	1	0	1	0	1	0	1	0	1	-34400	3

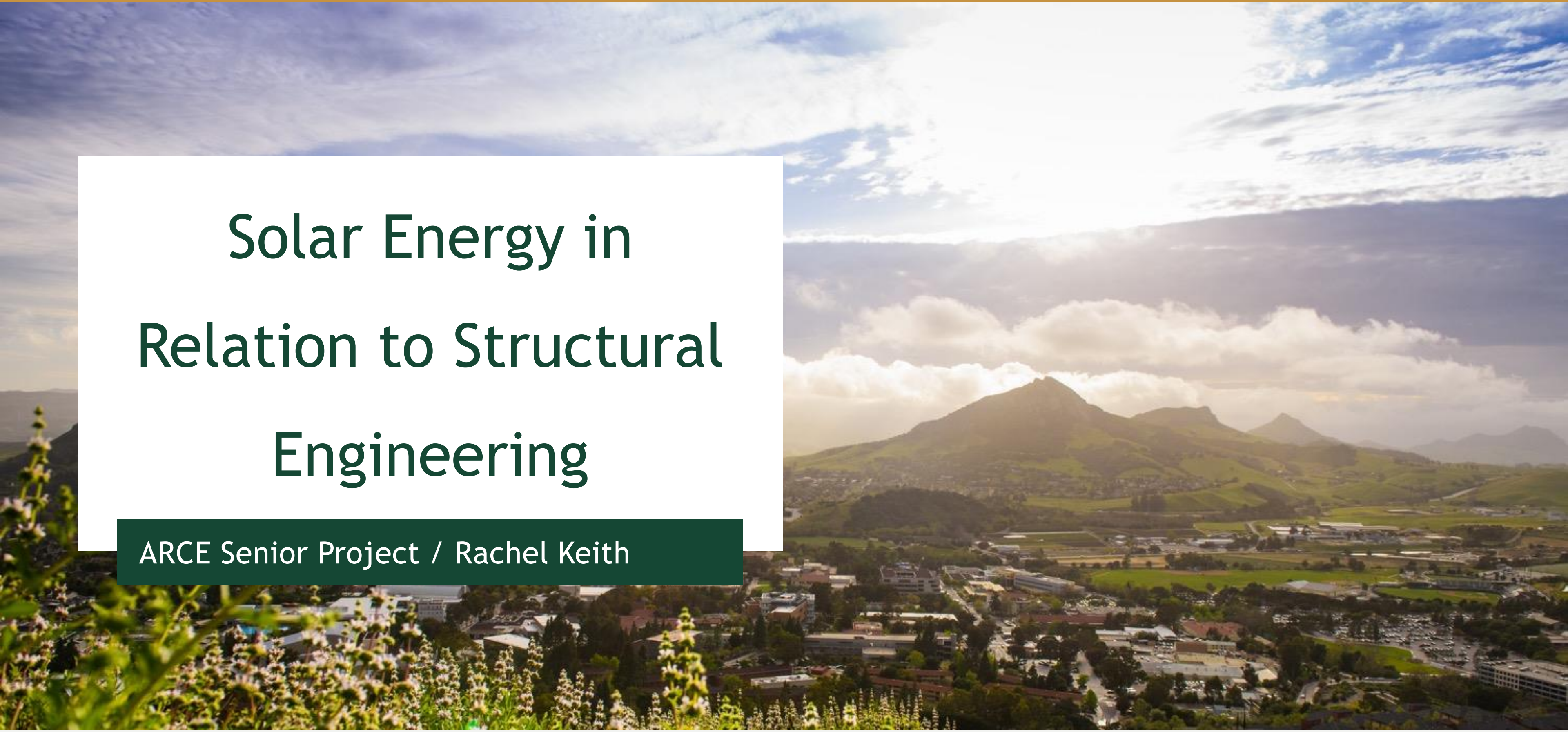
Envelope Member Section Forces (Continued)

	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
117		4	max	0	14	-792	14	0	14	0	14	0	14	-11880	14
118			min	0	1	-1720	3	0	1	0	1	0	1	-25800	3
119		5	max	0	14	-1584	14	0	14	0	14	0	14	0	14
120			min	0	1	-3440	3	0	1	0	1	0	1	0	1
121	Building 4 Joist 75% Solar	1	max	0	14	3555	3	0	14	0	14	0	14	0	14
122			min	0	1	1563	13	0	1	0	1	0	1	0	1
123		2	max	0	14	1835	3	0	14	0	14	0	14	-11670	14
124			min	0	1	771	13	0	1	0	1	0	1	-26950	3
125		3	max	0	14	115	3	0	14	0	14	0	14	-15420	14
126			min	0	1	-35	1	0	1	0	1	0	1	-36700	3
127		4	max	0	14	-813	14	0	14	0	14	0	14	-11250	14
128			min	0	1	-1605	3	0	1	0	1	0	1	-29250	3
129		5	max	0	14	-1437	14	0	14	0	14	0	14	0	14
130			min	0	1	-4245	3	0	1	0	1	0	1	0	1
131	Building 4 Joist 25% Solar	1	max	0	14	4356.25	3	0	14	0	14	0	14	0	14
132			min	0	1	1395	13	0	1	0	1	0	1	0	1
133		2	max	0	14	2656.25	3	0	14	0	14	0	14	-9990	14
134			min	0	1	603	13	0	1	0	1	0	1	-35062.5	3
135		3	max	0	14	106.25	3	0	14	0	14	0	14	-12900	14
136			min	0	1	-35	1	0	1	0	1	0	1	-48875	3
137		4	max	0	14	-645	14	0	14	0	14	0	14	-9570	14
138			min	0	1	-2443.75	3	0	1	0	1	0	1	-37187.5	3
139		5	max	0	14	-1269	14	0	14	0	14	0	14	0	14
140			min	0	1	-4993.75	3	0	1	0	1	0	1	0	1
141	Building 6 TJI Original	1	max	0	14	3408	3	0	14	0	14	0	14	0	14
142			min	0	1	892.8	13	0	1	0	1	0	1	0	1
143		2	max	0	14	1704	3	0	14	0	14	0	14	-4017.6	14
144			min	0	1	446.4	13	0	1	0	1	0	1	-15336	3
145		3	max	0	14	0	14	0	14	0	14	0	14	-5356.8	14
146			min	0	1	0	1	0	1	0	1	0	1	-20448	3
147		4	max	0	14	-446.4	14	0	14	0	14	0	14	-4017.6	14
148			min	0	1	-1704	3	0	1	0	1	0	1	-15336	3
149		5	max	0	14	-892.8	14	0	14	0	14	0	14	0	14
150			min	0	1	-3408	3	0	1	0	1	0	1	0	1
151	Building 6 TJI 100% Solar	1	max	0	14	1968	3	0	14	0	14	0	14	0	14
152			min	0	1	892.8	13	0	1	0	1	0	1	0	1
153		2	max	0	14	984	3	0	14	0	14	0	14	-4017.6	14
154			min	0	1	446.4	13	0	1	0	1	0	1	-8856	3
155		3	max	0	14	0	14	0	14	0	14	0	14	-5356.8	14
156			min	0	1	0	1	0	1	0	1	0	1	-11808	3
157		4	max	0	14	-446.4	14	0	14	0	14	0	14	-4017.6	14
158			min	0	1	-984	3	0	1	0	1	0	1	-8856	3
159		5	max	0	14	-892.8	14	0	14	0	14	0	14	0	14
160			min	0	1	-1968	3	0	1	0	1	0	1	0	1
161	Building 6 TJI 75% Solar	1	max	0	14	2037	3	0	14	0	14	0	14	0	14
162			min	0	1	880.2	13	0	1	0	1	0	1	0	1
163		2	max	0	14	1053	3	0	14	0	14	0	14	-3942	14
164			min	0	1	433.8	13	0	1	0	1	0	1	-9270	3
165		3	max	0	14	69	3	0	14	0	14	0	14	-5205.6	14
166			min	0	1	-21	1	0	1	0	1	0	1	-12636	3
167		4	max	0	14	-459	14	0	14	0	14	0	14	-3790.8	14
168			min	0	1	-915	3	0	1	0	1	0	1	-10098	3
169		5	max	0	14	-804.6	14	0	14	0	14	0	14	0	14
170			min	0	1	-2451	3	0	1	0	1	0	1	0	1
171	Building 6 TJI 50% Solar	1	max	0	14	2244	3	0	14	0	14	0	14	0	14
172			min	0	1	842.4	13	0	1	0	1	0	1	0	1
173		2	max	0	14	1260	3	0	14	0	14	0	14	-3715.2	14
174			min	0	1	396	13	0	1	0	1	0	1	-10512	3

Envelope Member Section Forces (Continued)

	Member	Sec		Axial[lb]	LC	y Shear[lb]	LC	z Shear[lb]	LC	Torque[lb-ft]	LC	y-y Moment[lb-ft]	LC	z-z Moment[lb-ft]	LC
175		3	max	0	14	276	3	0	14	0	14	0	14	-4752	14
176			min	0	1	-84	1	0	1	0	1	0	1	-15120	3
177		4	max	0	14	-396	14	0	14	0	14	0	14	-3412.8	14
178			min	0	1	-1260	3	0	1	0	1	0	1	-12168	3
179		5	max	0	14	-741.6	14	0	14	0	14	0	14	0	14
180			min	0	1	-2796	3	0	1	0	1	0	1	0	1
181	Building 6 TJI 25% Solar	1	max	0	14	2589	3	0	14	0	14	0	14	0	14
182			min	0	1	779.4	13	0	1	0	1	0	1	0	1
183		2	max	0	14	1605	3	0	14	0	14	0	14	-3337.2	14
184			min	0	1	333	13	0	1	0	1	0	1	-12582	3
185		3	max	0	14	69	3	0	14	0	14	0	14	-4298.4	14
186			min	0	1	-21	1	0	1	0	1	0	1	-17604	3
187		4	max	0	14	-358.2	14	0	14	0	14	0	14	-3186	14
188			min	0	1	-1467	3	0	1	0	1	0	1	-13410	3
189		5	max	0	14	-703.8	14	0	14	0	14	0	14	0	14
190			min	0	1	-3003	3	0	1	0	1	0	1	0	1

Appendix B



Solar Energy in Relation to Structural Engineering

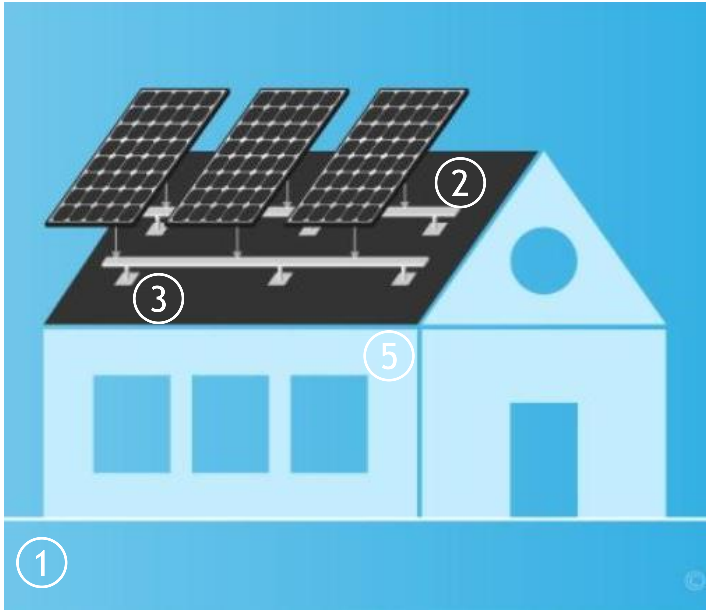
ARCE Senior Project / Rachel Keith

CAL POLY

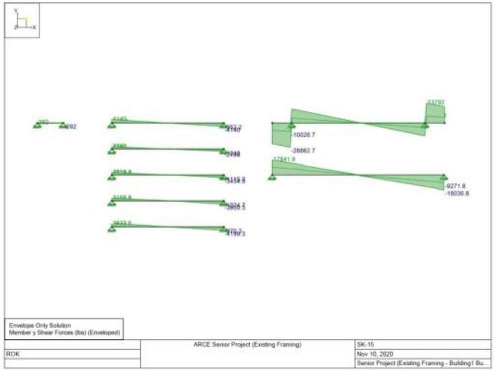
LEARN BY DOING

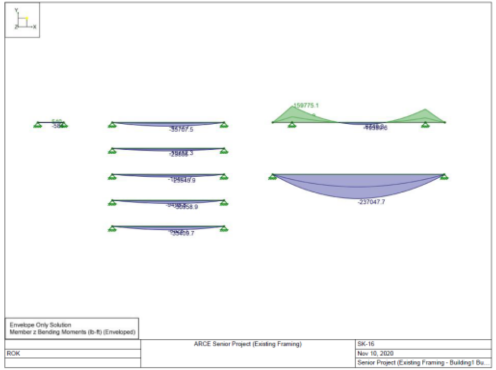
Calculations

1. Site Parameters
2. Racking Calculations
3. Anchorage Design
4. Equipment Mounting Design
5. Building Structure Check
    - Seismic Mass Allowances
    - Gravity Load Capacity



[1]





[1] EnergySage. “Solar Racking: What you Need to Know.” *EnergySage*, 22 Nov. 2019, https://news.energysage.com/solar-racking-overview/

Computer Programming

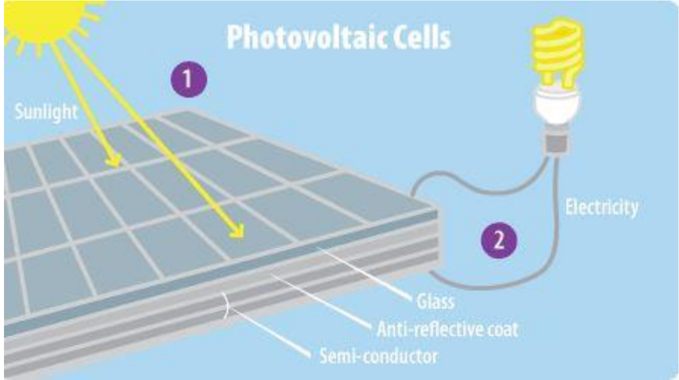
- Visual Basics for Applications
- Automates many steps in calculation procedure
- Used skills from previous ARCE classes
- Good exercise in problem solving and project engineering

[2]

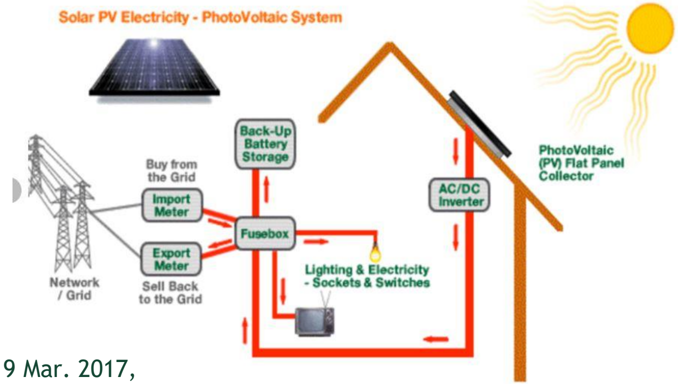
[2] Excel Consultant. "Microsoft VBA Logo." *excelconsultant*, Sept. 15 2017, https://www.excelconsultant.net/integration-and-automation-with-microsofts-vba/

Solar Energy Basics

- Solar photons excite semiconductor electrons
- Electrons move in electrical current
- Current extracted and sent…
    - Into a battery
    - Through an inverter to be changed into AC current
    - Into the household
    - Into the power grid



[3]



[4]

[3] United States Environmental Protection Agency. "Photovoltaic Cells." *Global Climate Change*, 9 Mar. 2017, https://archive.epa.gov/climatechange/kids/solutions/technologies/solar.html

[4] Devlin, Ger. "Schematic Example of a Solar Photovoltaic System." *ResearchGate*, Sept. 2011, https://www.researchgate.net/figure/Fig-1-Schematic-example-of-a-solar-photovoltaic-system-13_fig1_25259208

Solar Energy Impacts

- Economic
  - Owner costs, buy vs. lease, community economy
- Environmental
  - Clean energy source, habitat loss, material use, hazardous manufacturing
- Political
  - Government offered monetary incentives, public electric utilities vs. home solar installations
- Global
  - Competitive market

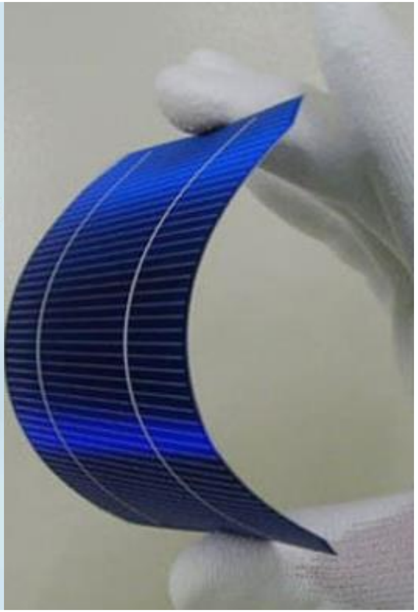
[5]

[5] Stillings, Jamey. "Desert oasis: The plant's 8 million solar panels power about 160,000 California homes" Time Magazine, 26 February 2015, https://time.com/3723592/inside-the-worlds-largest-solar-power-plant/

Future of the Industry

- Better batteries
- Increased cell efficiency
- New module types

[6]



[7]

[6] Arkana Energy. "Solar Battery House." *Arkana Energy*, n.d., https://arkanaenergy.com.au/solar-power-batteries-and-the-future-of-solar/
[7] Verma, Ayush. "NREL, First Solar Collaboration Enhance Thin-Film Solar Cells." *Saur Energy International*, 21 Aug. 2019, https://www.saurenergy.com/solar-energy-news/nrel-first-solar-collaboration-enhance-thin-film-solar-cells

What I Learned

- Structural Calculations
  - Learned by follow examples
  - Taught at internship
- VBA
  - Trial and error
  - Internet research
- Solar Basics and Impacts
  - Internet research
  - Personal work in the field
  - Speaking with knowledgeable field experts